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Geomorphology, stratigraphy and Holocene history of the Rockingham-Becher Plain, South-western Australia

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Abstract

The Rockingham-Becher Plain is a large, cuspate, beachridge system in the central portion of the Cape Bouvard-Trigg Island Sector of the inner Rottnest Shelf coast. The main geomorphic components in the area are shore-parallel Pleistocene aeolianite ridges and their associated intervening depressions, and the Holocene units of basins, slopes, banks/nearshore platforms, beaches, and beachridge/dunes. The Holocene sedimentary facies have generated distinctive suites of sediments and a relatively simple stratigraphy: the facies of the basin has formed the calcareous mud of the Bridport Calcilutite, the facies of the banks, slopes, and nearshore platforms have developed the bioturbated sediment of the Becher Sand, and the facies of the beaches, beachridges, and dunes have developed the Safety Bay Sand. Most of the Holocene sequence underlying the Rockingham-Becher Plain is comprised of these stratigraphy units in simple superposition.

Radiocarbon dating of the sequences indicates that the Holocene marine record begins at 7 980 C14 yrs BP, and that beach conditions were established along the fossil shoreline at 6 645 C14 yrs BP with relative sealevel at c + 2.5 m. Since then relative sealevel has steadily dropped and sediments have accreted rapidly to develop the broad beachridge plain. Isochron configuration shows that the plain developed asymmetrically with sediment increments accumulating preferentially on the southern portion of the complex. Palaeogeographic reconstructions for the 8 000 yr record presented in 2 000 yr intervals show a complex coastal history of progressive sediment accretion, with cuspate beachridge plain progradation, bank accretion centred on two major westward prograding banks, and concomitant limestone island/reef chain erosion.

Introduction

The subject matter of this paper, the Holocene coastal plain in the Rockingham and Becher Point area, is termed herein the Rockingham-Becher Plain (Figs 1 & 2). It occurs in the central part of the Cape Bouvard-Trigg Island Sector of southwestern Australia (Searle & Semeniuk 1985). This sector is characterized by complex nearshore bathymetry of Pleistocene ridges-and-depressions and extensive accumulations of Holocene sediments that form prograded plains of beachridges and sand dunes. The Cape Bouvard-Trigg Island Sector in particular is significant in that it contains the largest accumulations of Holocene sediment in this region.

Previous work on the Rockingham-Becher Plain has dealt with: Quaternary geomorphology and stratigraphy of the Point Peron area (Fairbridge 1950); sedimentation in Warnbro Sound (Carrigy 1956); Cainozoic stratigraphy and shallow hydrology (Passmore 1970); generalized stratigraphy and geomorphology (Seddon 1972); radiocarbon dating and sealevel history (Woods & Searle 1983; Searle & Woods 1986); development of submarine banks (Searle 1984); development of soils on the plain (Woods 1984); mapping of surface geologic units (Geology Survey of WA 1985); calcrete in the coastal sands and its use in Holocene climate history (Semeniuk & Searle 1985a; Semeniuk 1986a); the definition of the Becher Sand (Semeniuk & Searle 1985b); and the description of aeolian landforms

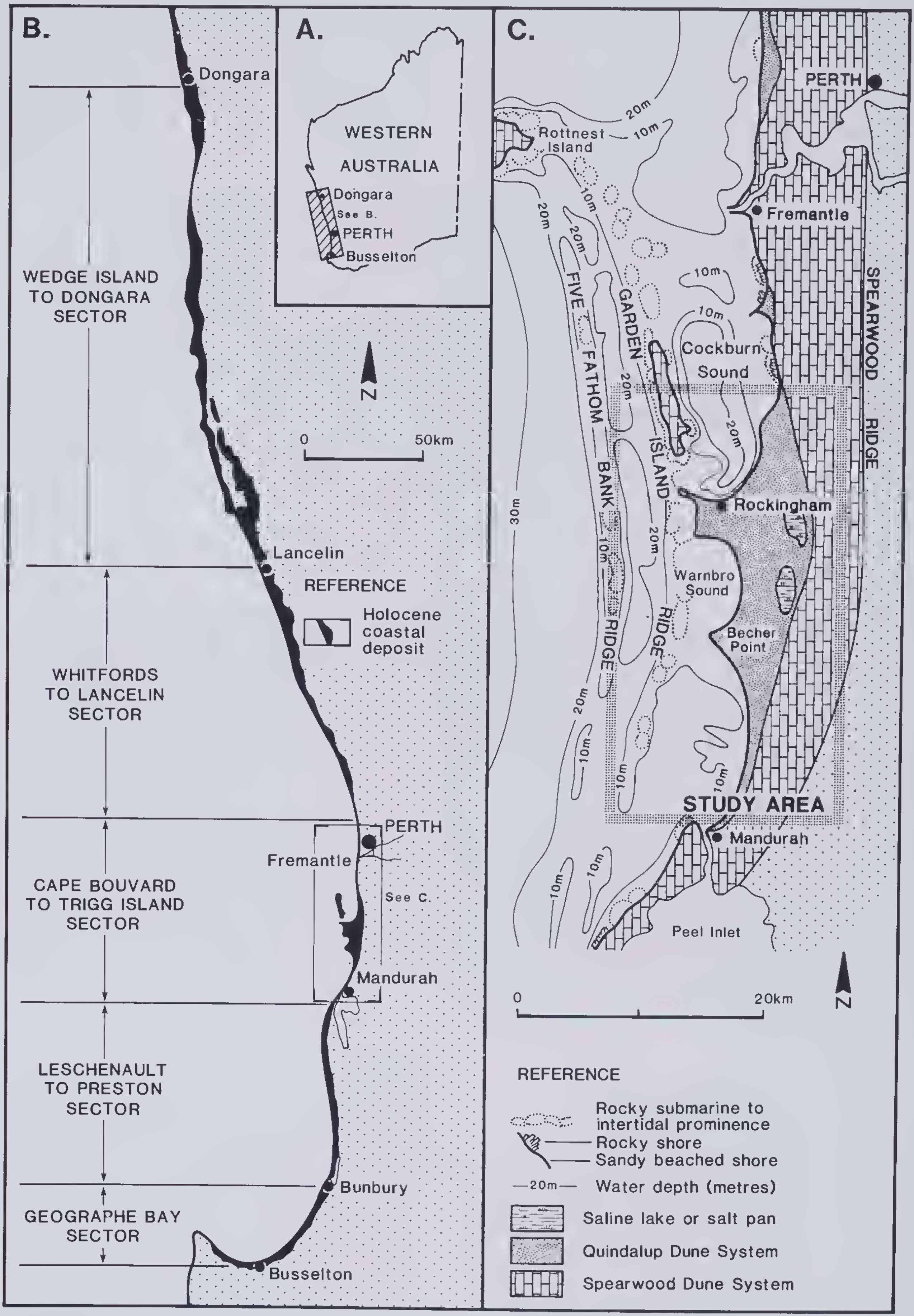

Figure 1 Locality diagram showing study area in the regional setting and in the local coastal sector setting.

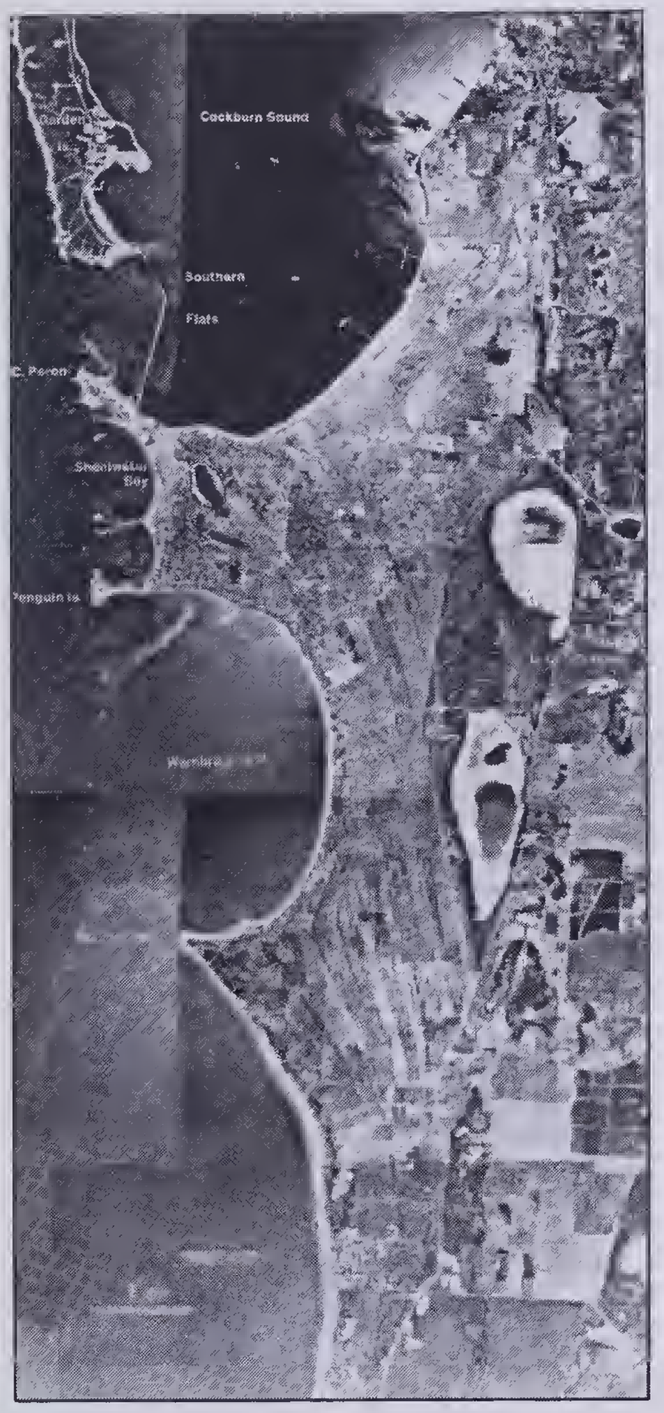

Figure 2 Aerial photograph of study area showing cuspate configuration of shoreline, the chain of islands and reefs extending from Garden I through Penguin I and further south, and the prominent lineation of the beachridge patterns.

(Semeniuk et al. 1987). These works, however, do not provide the detail on, and synthesis of, the available information on the geomorphology, sedimentology, stratigraphy and age structure of the study area to the level provided herein. In particular there is still a lack of appreciation of the detailed Holocene history of the area, some of which has worldwide significance. Accordingly, this paper integrates information from the area to demonstrate how the Holocene coastal deposits formed, and to highlight its value as a natural feature of scientific significance.

Methods

Various methods were used to obtain data for this study including stratigraphic analysis, surface mapping of sediments by diver, aerial photography, granulometry and petrology of selected sediment, and radiocarbon analysis of selected shell and peat (Fig. 3).

The Holocene stratigraphy was investigated using reverse circulation coring to depths of 33 m with continuous sample recovery, percussion coring to retrieve cores to depths of 20 m, auger drilling to the water table, trenching (to 3 m below the water table using dewatering pumps) and natural exposures such as wind-eroded surfaces and cliff faces. The stratigraphy offshore was investigated with "air-lift" drilling and hand-driven cores. The "air-lift" drilling uses casing pipe and a smaller diameter compressed air powered suction pipe; penetration in excess of 10m is possible in sediments. Stratigraphic study sites were related to AHD by surveying.

The geomorphology and bathymetry of the area were documented using vertical and oblique aerial photography (at scales from 1:40 000 to 1:4 000), water penetrating aerial photography, topographic maps and bathymetric charts, and by surveying. Submarine mapping and sampling was carried out by numerous diver traverses, replicate grid sampling of substrates and by analysis of water penetrating aerial photographs. Alongshore sampling of the beach and foredune sediments also was carried out. Sediment samples were petrographically analysed using thin sections cut from resin-impregnated blocks. Selected samples were granulometrically analysed using sieves at either 0.5 or 1 phi intervals.

The age structure of the sedimentary sequence was determined by radiocarbon dating of selected shells and peat from discretely determined stratigraphic levels. This stratigraphic approach and the criteria for material selection are detailed in Woods & Searle (1983) and Searle & Woods (1986).

Regional Setting

The Rockingham-Becher Plain is located in the southern- central part of the Cape Bouvard-Trigg Island Sector. The nearshore-onshore geomorphology and bathymetry of this entire sector is dominated by a series of shore-parallel (or nearly so) submarine to emergent Pleistocene aeolianite ridges and associated depressions. These are been termed from west to east (Fig. 1; Searle 1984; Searle & Semeniuk 1985): **Five Fathom Bank Ridge; Sepia Depression; Garden Island Ridge; Warnbro-Cockburn Depression;** and **Spearwood Ridge.**

The ridges vary in relief from a few metres to in excess of 80m above the floor of adjacent depressions, and in continuity from continuous to discontinuous. The Spearwood Ridge which is part of the Spearwood Dune System (McArthur & Bettenay 1960) forms the mainland shore, and forms a topographic barrier between the inner

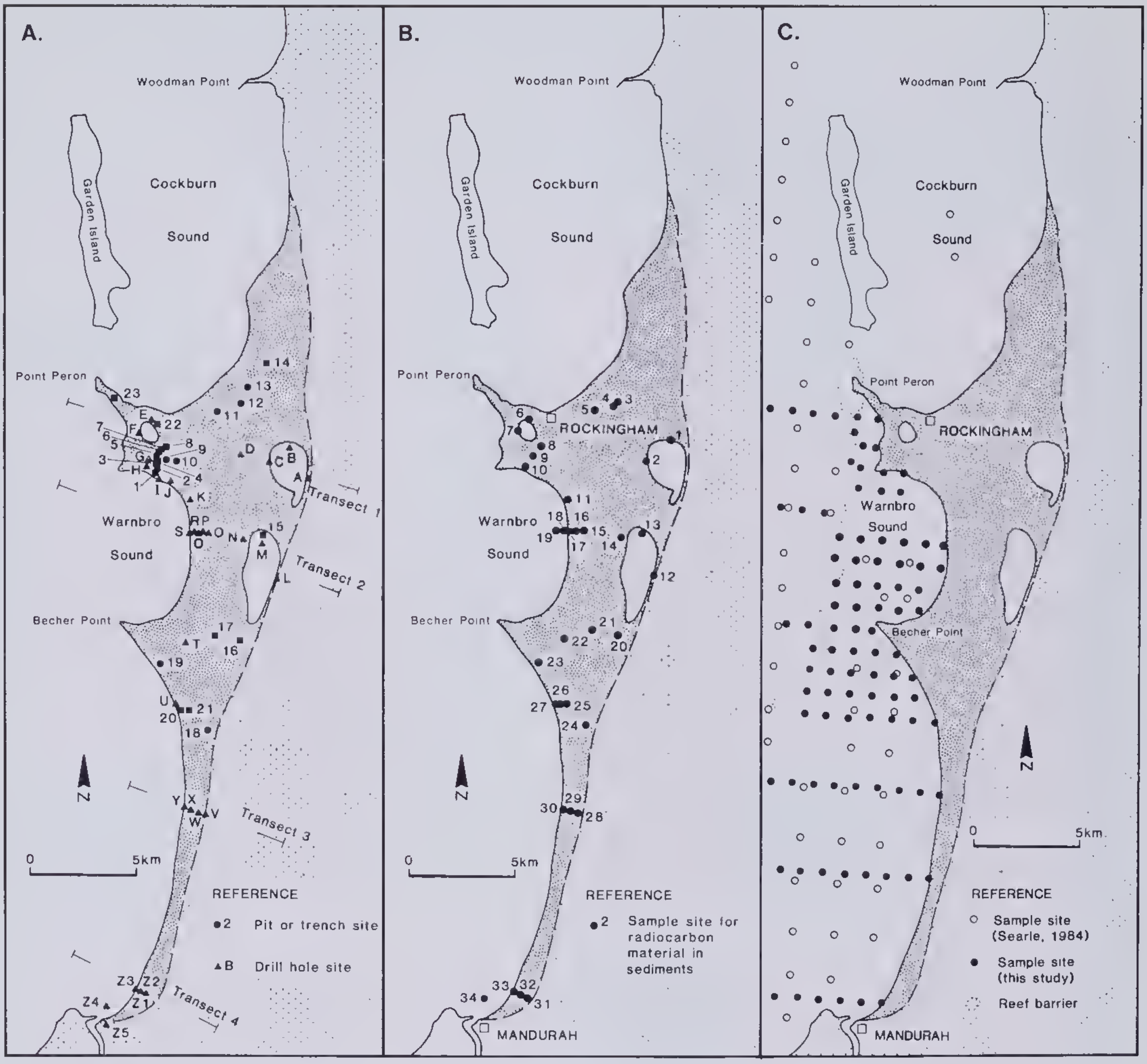

Figure 3 Sampling sites.

A Drill, trench and pit sites.
B Sample sites for radiocarbon material from beach sediment for use in Table 2 and Figure 6.
C Location of underwater sampling sites and diver traverses.

Rottnest Shelf and the low Swan Coastal Plain to the east (Fig. 1). The Garden Island Ridge is situated some 10 km offshore to the west. Holocene sediments have accumulated mostly in the depression between the Spearwood Ridge and the Garden Island Ridge.

The offshore physical oceanographic pattern along this coast is typical of the region (Steedman & Craig 1983; Searle & Semeniuk 1985). The area is wave dominated and microtidal (Hodgkin & DiLollo 1957). The inshore oceanographic pattern is specific to this sector (Searle & Semeniuk 1985). In summer the prevailing waves are oceanic swell deriving from between west and southwest, supplemented by locally-generated southwest wind waves developed by seabreezes. The complex nearshore bathymetry dampens, refracts and diffracts the swell developing complicated convergence and divergence of wave orthogonals. Locally-generated wind waves are of shorter period and wavelength, and are less modified by the bathymetry. In winter, locally-generated storm waves, which approach mainly from northwest and west, also are a significant influence on coastal processes. The dominant sand-shifting winds in the area are summer seabreezes from the southwest.

The Rockingham-Becher Plain

The natural boundaries of the Rockingham-Becher Plain are (Fig. 1): Garden Island Ridge to the west; Cockburn Sound and Garden Island to the north; the mainland Spearwood Ridge to the east; and the Peel-Harvey estuary exchange channel at Mandurah to the south. The subaerial coastal area of the Rockingham-Becher Plain essentially contains two coalesced triangular beachridge plains or cuspate forelands (Woods & Searle 1983) which are localised behind the islands, reefs and rocky prominences of the Garden Island Ridge (Fig. 1). These types of beachridge terrains are termed cuspate forelands (Bird 1976) or accretionary cusps (Semeniuk & Searle 1986a). The area also contains a variety of submarine geomorphic units that include banks, and basins.

In order to assemble the available information to a stage where the Holocene palaeogeography of the coast can be reconstructed it is necessary to describe the geomorphology, sedimentary facies, stratigraphy, age structure, and sealevel history of the Rockingham-Becher system.

Geomorphology

The various coastal geomorphic units in this area either have been developed during the Holocene as a result of sedimentary accretion, or are erosional remnants of Pleistocene landforms. In order from basement and/or deep water upwards: they are: Pleistocene ridges, basins, banks, beach zone, and beachridge and dune plain (Fig. 4).

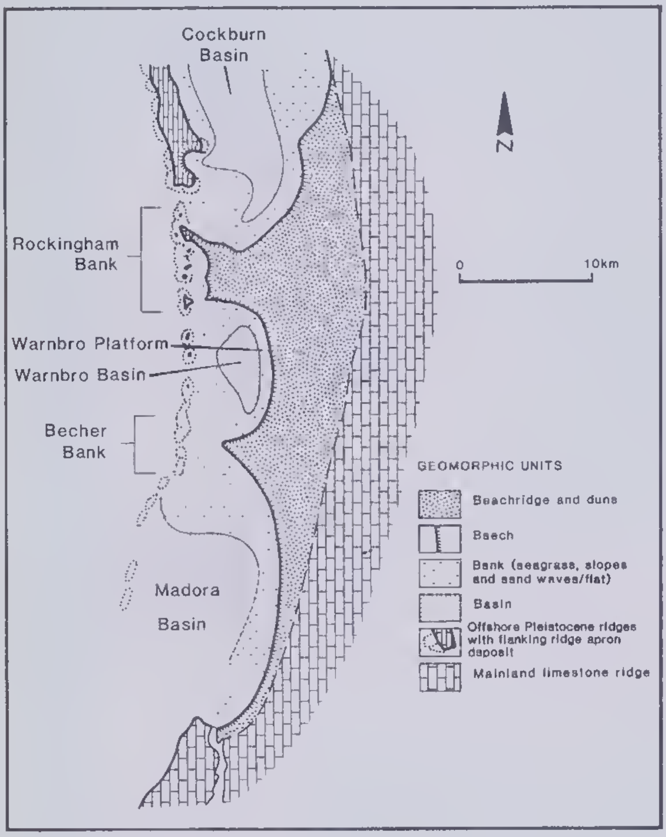

Figure 4 Geomorphic units of the study area.

Pleistocene ridges

The eroded remnants of the Pleistocene aeolianite ridges (mainly Garden Island Ridge and Spearwood Ridge) have had a major control on Holocene sedimentation and hence geomorphology. As such it is important to appreciate their influence on Holocene geomorphic history. The aeolianites of the ridges are variable in lithification, from unlithified to (most commonly) semilithified to locally fully indurated (calcrete capstone). This has implications for the rates of erosion of the ridges and for supply of unlithified sand to the Holocene sedimentary systems.

The Garden Island Ridge extends discontinuously north from Cape Bouvard (where it merges with the Spearwood Ridge) through to Penguin Island, Cape Peron, Garden Island and Carnac Island, before curving broadly to terminate at the western extremity of Rottnest Island (Fig. 1). The ridge rises from depths of 15 to 20 m to form a submarine to emergent chain of rocky reefs, pinnacles and islands. The islands of the Garden Island Ridge have shorelines of low (2 to 5 m high) rocky cliffs, headlands and interspersed pocket beaches (Fairbridge 1950; Semeniuk & Johnson 1985). Stacks, intertidal terraces, notches, collapsed remnants of platforms and pinnacles on the adjacent seafloor, and cliffed primary dunes along the shoreline indicate that the ridge is still eroding. Constructional platforms of beachrock are developed on the western shores of the major islands.

The Spearwood Ridge rises to 80 m above the floor of the Cockburn-Warnbro Depression. It is largely covered by Holocene dunes to the south but is exposed as a shoreline unit to the north. In places the main ridge is fronted to the west by a second, lower ridge, which rises to within a metre of present sealevel. This lower ridge is largely buried by Holocene marine sediments but it crops out on the seabed at Pt James.

Basins

Deep water areas (16-25 m depths) are termed basins. There are three basins: Warnbro Basin, Cockburn Basin and Madora Bay Basin. They are flanked by relatively steep slopes of the adjoining banks and platforms to the east, north and south, and by the Garden Island ridge to the west. Below about the 16m isobath in the Warnbro Basin and the 18 m isobath in Cockburn Basin, the basin floors slope gently to maximum depths of 19m and 25m respectively. The Madora Bay Basin exhibits an even more gentle slope from the adjoining banks to deeper water. The basin floors lack local bathymetric features and are devoid of seagrass meadow cover.

Banks

Banks are shallow water submarine geomorphic units, underlain by Holocene sediment. that extend across the entire width of the Warnbro-Cockburn Depression and form aprons and promontories around the subaerial sandy points in the area, and platforms around the intervening basins (Fig. 4). The two main banks in the area are the Rockingham and Becher banks. The (subaerial) Becher Point promontory, which extends part of the way towards the Garden Island Ridge from the Spearwood Ridge, is surrounded by a wide bank. In contrast, the Rockingham promontory, which links with the Garden Island Ridge at Point Peron, has smaller surrounding areas of banks. Between the two major east-west promontory axes, there is a narrow fringing platform (about 100 m wide) termed here the Warnbro Platform, around the Warnbro Sound shore. A similar platform is developed on the northern Rockingham Bank along the Cockburn Sound shore.

Seaward of the surf zone the surfaces of banks slope gently towards the basins to depths of about 6m. Below this depth contour the banks slope steeply (up to 20°) into the Warnbro Sound basin or the Cockburn Sound basin. Slopes from the Becher Bank south into the Madora Bay Basin are more gradual, only locally exceeding 5°. To the west the banks abut the flank of the Garden Island Ridge. The banks are surfaced by seagrass meadows, sand waves or sand flats. The more sheltered parts of bank surfaces support dense seagrass meadows. The Rockingham Bank supports particularly dense meadows while on the Becher Bank seagrass cover is more localized and patchy. Sandy shoals are also developed locally on the bank surfaces, and may be developed to a stage where they are continuously emergent.

Beach zone

This zone contains the active beach and beachridge (or foredunes). The morphology of the beach zone may vary significantly due to seasonal coastal processes and variable incident waves and currents. Subaerial beach profiles vary from narrow (10 m) and steep, to wide (about 100m) and gently sloping. The morphology of the contemporary beachridges varies from low (2-5 m) and only partially stabilized by vegetation, to high (6 to 10 to 22 m high) and well stabilized by vegetation (except in discrete active blowout areas).

Beachridge and dune plain

In plan the beachridge and dune plain (Quindalup Dunes of McArthur & Bettenay 1960) of the area is an irregular shape, with a straight, well-defined eastern margin where it abuts the Spearwood Ridge, and a cuspate or scalloped western margin. To the north, adjacent to Cockburn Sound, the plain narrows rapidly against the Spearwood Ridge (Fig. 1). To the south, the plain narrows gradually against the Spearwood Ridge before it terminates against the Peel-Harvey estuary exchange channel. The plain extends for 40 km along the coast and at its widest is 10 km. The mean elevation of the plain is 5m along the eastern margin and falls gradually to 2 m at the modern coast.

The surface of the plain is characterized by well defined linear beachridges and intervening swales (Fig. 2), that have been locally reworked into small parabolic dunes. There are over 100 beachridges and swales. The precise number is difficult to determine due to local acolian modification of the normally well defined ridges. Individual beachridges usually are 2 to 5m higher than the intervening swales, and 50 to 100 m apart. There is also a recurring pattern of higher beachridges that have a relief of 6 to 10m and, in a few instances, up to 22 m. Commonly these higher ridges and associated deep linear swales are separated by sets of about 3 to 6 lower ridges. Individual ridges and swales can be traced for over 20 km along the north-south length of the plain (Fig. 2). In plan the beachridge trends are parallel and concordant, except in the more seaward parts of the cuspate promontories and adjacent to the Spearwood Ridge. In these locations younger sets of beach-ridges obliquely truncate older sets.

The beachridges and swales generally are stabilized by vegetation. However, there has been some local aeolian modification and this varies from minor sculpturing, to complete reworking of ridges into blowouts and landward migrating parabolic dunes extending up to 750 m inland. Significantly, aeolian reworking is largely restricted to the higher-than-normal ridges; the regular lower relief beachridges remain mostly unaffected. The blowouts and parabolic dunes vary from unvegetated and actively forming to well stabilized by vegetation. However, the presently active blowouts and parabolic dunes occur at, or close to, the present coast.

Sedimentary facies

In the study area the variable incident waves and currents interact with the complex nearshore bathymetry to produce a broad spectrum of facies and lithotopes in which distinct suites of sediment types are formed. The sedimentary facies are, in order from basement and/or deep water upwards (Fig. 5): ridge aprons; basin; bank (incorporating slope, seagrass, sand wave and sand flat lithotopes): beach: and beachridge and dune.

Ridge apron facies

This facies forms aprons of sediment that lie adjacent to the limestone ridges. The dominant coastal processes are erosion of the Pleistocene aeolianite, and transport into deeper water. The sediments form wedges or ribbons of laminated, or bedded to cross layered, coarse to medium sand and gravelly, shelly sand. Sedimentary components are skeletons, derived from the adjoining rocky shores, lithoclasts and quartz.

Basin facies

The sediments of the basin facies form on the basin floors. These low energy deep water areas accumulate the slowly settled fine sediment entrained in the water from the more energetic bank environments. Only under extreme and short lived situations do waves or currents rework the basin floor. An exception is the Madora Bay Basin which is substantially more exposed to waves and currents. As a result sediment reworking is more frequent and can occur under moderate to heavy swells and strong wind driven currents.

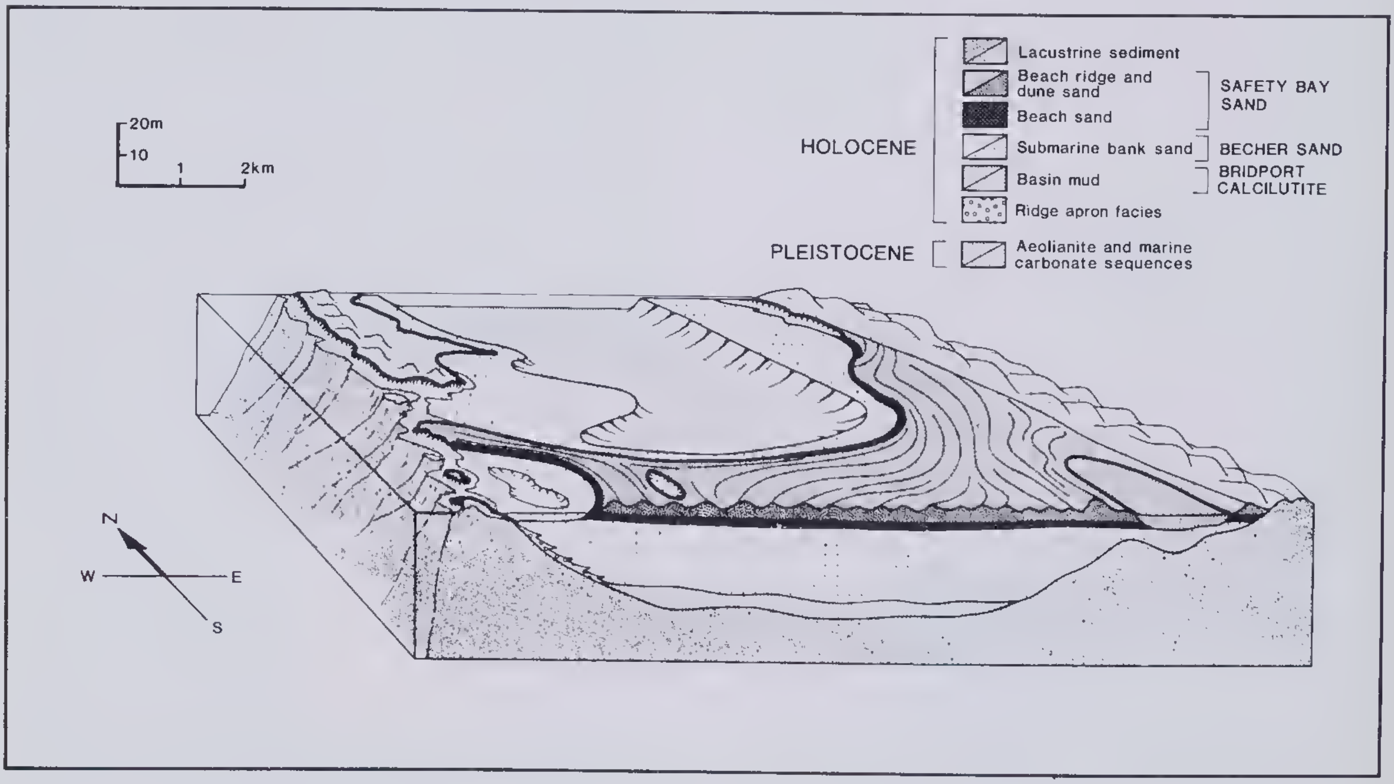

Figure 5 Three-dimensional diagram illustrating the relationship between geomorphic units, sedimentary facies and stratigraphic units.

Sediments of the basin facies generally are grey carbonate muds. The Madora Bay Basin sediments, in contrast, are fine to medium sand and are lighter grey. Bioturbation by infauna in all the sediments results in little or no preservation of primary sedimentary structures.

Bank facies

The bank facies includes the lithotopes of the bank slope, seagrass-covered surfaces, sand waves and sand flats.

Bank slope lithotope.—A distinct sedimentary lithotope occurs on the bank slopes to depths where the slopes merge with the basin floors. Transport mechanisms involve downslope gravity movement of sediment impelled over the bank edges by cross-bank transport. The steepness of the slopes and the marked decrease in wave and current energy downslope ensure that transport is unidirectional towards the basin.

The diagnostic characteristics of sediments in this lithotope are their degree of sorting and distribution down the slope. The sediments are grey, well sorted medium to fine sands, with fine sand on the lower slopes and medium sand on the upper slopes. The sediments are texturally and compositionally similar to the seagrass lithotope from which they are derived but lack large skeletal fragments. Slope-parallel laminations are formed and preserved in the upper slope sediments. Lower slope sediments are structureless due to a lack of textural variability or to bioturbation by infauna.

Seagrass lithotope.—The sediments of the seagrass lithotope accumulate under the extensive seagrass-covered bank surfaces. Sedimentary processes in the environment include *in situ* skeletal grain production, accumulation of skeletal grains in seagrass meadows, bioturbation by fauna, accumulation of seagrass material, cross-bank transport by waves and currents on surfaces not covered by seagrass meadow, and trapping/binding/baffling of sediment by seagrasses.

Sediments of the seagrass lithotope are sand and shelly sand varying to muddy sand and shelly sand. They are composed predominantly of sand-and gravel-sized skeletal material with variable seagrass detritus, fibres and carbonate mud. Locally, the sediments contain quartz sand, and adjacent to Pleistocene limestone outcrops there are substantial quantities of lithoclast sand. The sediments generally are grey, bioturbated and root-structured, and consequently there is a paucity of physical sedimentary structures. The grey coloration is due to staining by iron sulphide.

Sand wave/sand flat lithotope.—Sediments of the sand wave and sand flat lithotope form immediately seaward of the inshore zone. The seaward and depth limit of this lithotope, as defined by the occurrence of seagrass meadows, is variable and dependant on the local incident wave energy. In the protected environments of Cockburn Sound and Warnbro Sound the transition occurs at depths of 1 m, and the sedimentary products are almost indistinguishable from the lower beach facies. In the more exposed Madora Bay setting, the facies transition occurs at depths in excess of 3 m.

Sedimentation is dominated by the formation and migration of sand waves up to lm in amplitude. The sediments of this lithotope are well sorted medium sands composed largely of skeletal fragments and lithoclasts. The quartz content is minor and significantly lower than the beach facies but higher than the seagrass lithotope. Sedimentary structures in the sediment include layering and cross layering with concordant sets reaching up to lm in thickness; maximum dip angles of cross layering are about 15°.

Beach facies

The beach facies occurs along the shore of the active beach between the inshore zones and storm water level. The processes of sedimentation in this facies include wave and current transport, physical and biological swash zone processes, storm accumulation and erosion, and aeolian transport. The beach facies has been subdivided into several zones, *viz.*, backshore (berm), swash and shallow subtidal inshore, and sediments of the facies exhibit a lateral sequence of grain size and structures that correspond to processes operating within these zones (Semeniuk & Johnson 1982). Beach sediments consist of medium to coarse skeletal and lithoclast carbonate sand with a minor, variable quartz component. Usually the quartz content of the swash zone is significantly higher than adjoining zones and other facies. The sequence of sedimentary structures formed in each zone of the beach facies is: layered, medium sand and shelly sand in the backshore zone; laminated, medium to coarse shelly sands in the swash or foreshore zone, with bedded/laminated bubble sand in the upper swash zone; and cross- and trough-layered, medium to coarse sand and shelly sand in the inshore zone.

Beachridge and dune facies

The beachridge and dune facies occurs along the modern coastal zone adjoining the beach and is the product of aeolian transport inland from the beach. Sediments of the beachridge and dune facies are well sorted, medium and fine sand composed of rounded skeletal fragments, carbonate lithoclasts and minor well rounded quartz. Large scale cross layering is typical, except where vegetation has prevented the formation of structures or rootlets have disrupted them.

Stratigraphy

Components of the stratigraphy have been described previously by Passmore (1970) and Semeniuk & Searle (1985b). The area contains the type localities for 4 Quaternary formations relevant to this study: 1)Safety Bay Sand (Passmore 1970, redefined by Semeniuk & Searle 1985b); 2)Becher Sand (Semeniuk & Searle 1985b); 3)Bridport Calcilutite (Semeniuk & Searle 1987); and 4)Cooloongup Sand (Passmore 1970). In addition, the Tamala Limestone (Playford *et al.* 1976) occurs in the area. For purposes of this paper the Tamala Limestone will be considered to be the foundation or basement unit in the area.

Pleistocene-Holocene contact

The Pleistocene-Holocene contact in this area is an unconformity interface cut into Tamala Limestone, or yellow quartz sand (Cooloongup Sand), or ?Plio-Pleistocene mud. Thus the unconformity is coincident with the buried Pleistocene ridge-and-depression palaeotopography (Figs 5 & 6). The Holocene sequence in the main abuts a steep cliff cut into Tamala Limestone along the Spearwood Ridge to the east, and pinches out against, or onlaps Tamala Limestone along the Garden Island Ridge to the west. In the depression between the two ridges the unconformity surface is marked by calcreted Tamala Limestone with variable cover of (yellow) quartz sand. In the Singleton Beach area (transect 3), the Holocene deposits rest on a grey clay deposit, determined by palynology to be ?Plio-Pleistocene (J. Backhouse, pers. comm.).

Holocene units

The Pleistocene/Holocene unconformity is overlain by a variety of Holocene units. These units, described in order from the Pleistocene-Holocene contact upwards, include (Table1 and Figs 5, 6 & 7): local rocky shore deposits; local estuarine mud; Bridport Calcilutite; Becher Sand; and Safety Bay Sand.

The main Holocene units in the area are the Bridport Calcilutite, Becher Sand and Safety Bay Sand. Rocky shore deposits are confined to the flanks of the mainland shore and the Garden Island Ridge and usually are buried by younger Holocene units. Local deposits of shelly estuarine mud (referable to the Leschenault Formation: Semeniuk 1983) occur as thin layers in the former hollows in the Cockburn-Warnbro Depression; these deposits also are buried by younger Holocene units. The stratigraphic relationships of the various units and their relationship to geomorphic units is summarized in Figure 5. The bulk of the Rockingham-Becher Plain is underlain by the Safety Bay Sand and Becher Sand. There is a consistent stratigraphic relationship between these two formations throughout most of the area wherein the Becher Sand forms the contemporary banks and extends under the beachridge plains to underlie the Safety Bay Sand. In the San Remo area (transect 4, Fig. 6), however, the Safety Bay Sand overlies a sheet of shelly (rocky shore) deposit and locally, an estuarine sediment unit.

The Bridport Calcilutite consists of grey muddy carbonate sediment which formed in the basin facies. The unit occupies former depressions in the underlying palaeotopography and is the lowermost unit of the main Holocene deposits, overlying either the other minor Holocene units or the Pleistocene units. The Becher Sand is composed of sediment formed in the bank facies (Semeniuk & Searle 1985b); it is mostly grey, bioturbated sand and shelly sand with local seagrass fibre.

The Safety Bay Sand is composed of sediment formed in the beach, beachridge and dune facies. For purposes of stratigraphy and palaeo-environmental interpretations the Safety Bay Sand is subdivided into a beach (littoral) facies and a beachridge/dune (aeolian) facies (following Semeniuk & Searle 1986b). A notable feature of the sediments of the Safety Bay Sand is that they typically exhibit a small scale stratigraphic sequence of structures, lithology and grainsize, reflecting depositional environmental gradients within the facies and transitions between the facies (see Semeniuk & Johnson 1982; and Woods & Searle 1983). This stratigraphic sequence is consistently encountered ubiquitously beneath the beachridge plain; from the surface the sequence is (Fig. 7):

- cross-layered to structureless aeolian beachridge and dune sand with *Spirula* and *Sepia* skeletons near the base, grading down into
- horizontal to seaward dipping, layered medium sand and shelly sand, with *Spirula* and *Sepia* skeletons and *Ocypode* burrows (backshore unit)
- seaward-dipping laminated medium to coarse shelly sand with *Donax* and *Glycymeris* (swash unit), and locally preserved bubble sand in the upper part,
- cross-and trough-layered medium and coarse sand and shelly sand (inshore unit).

The base of the sequence rests on bioturbated to crudely layered sand, shelly sand and muddy sand of the Becher Sand.

In the nearshore submarine area north of Mandurah the stratigraphy consists of a sheet of fine/medium sand about 1.5m thick, overlying a 0.5m thick gravel deposit of shells (Fig. 7). This gravel layer also occurs under the Safety Bay Sand along transect 4 (Fig.6) in the San Remo area. The-shells are a mixture of fauna derived from environments of rocky shores, seagrass meadows, beach zones and an estuary.

Age structure of Rockingham-Becher plain

The materials used for radiocarbon analyses and their ages are described in Table 2. The radiocarbon results are used to determine: the initiation and history of Holocene

Table 1

Description of Holocene Stratigraphic Units

Unit	Description	Thickness	Stratigraphic Relationships	Occurrence
Safety Bay Sand	prism, or sheet of laminated, x-laminated to structureless sand and shelly sand	mostly 2-6 m	sharp contact with underlying Becher Sand; locally sharp contact with rocky shore deposits	underlies much of the plain and forms the sub-aerial surface of the plain
Becher Sand	wedge or prism of bioturbated, structureless to crudely layered grey shelly sand, sand and muddy sand; local seagrass fibre	up to 20 m	sharp contacts with underlying Bridport Calcilutite and with overlying Safety Bay Sand; locally gradational contact with underlying Leschenault formation or rocky shore deposits, or Cainozoic mud	underlies much of the plain; forms contemporary surface of the Rockingham and Becher banks
Bridport Calcilutite	wedge, or ribbon, or sheet of structureless carbonate mud and shelly	usually 2 m thick, up to 6 m thick	gradational contact with underlying Cooloongup Sand and Leschenault Formation; sharp contact with overlying Becher	occurs as buried deposit towards middle and western portion of the plain; forms contemporary surface in Warnbro Sound
Leschenault Formation	lens of grey/black clay mineral mud and muddy sand with estuarine shell assemblage	<1 m	gradational contact with underlying Cooloongup Sand; or sharp contact, marked by pebbles with Tamala Limestone overlain gradationally by Becher Sand or Bridport Calcilutite	in former deep depressions underlying the Rockingham-Becher Plain
Rocky shore deposits and ridge apron deposits	sheet and wedge shaped unit of gravelly and shelly lithoclastic skeletal sand	<1 m	overlies Tamala Limestone; overlain by Becher Sand or Safety Bay Sand	Usually located on flank of Spearwood Ridge and on flank of Garden Island Ridge but also forms basal sheet in the San Remo area

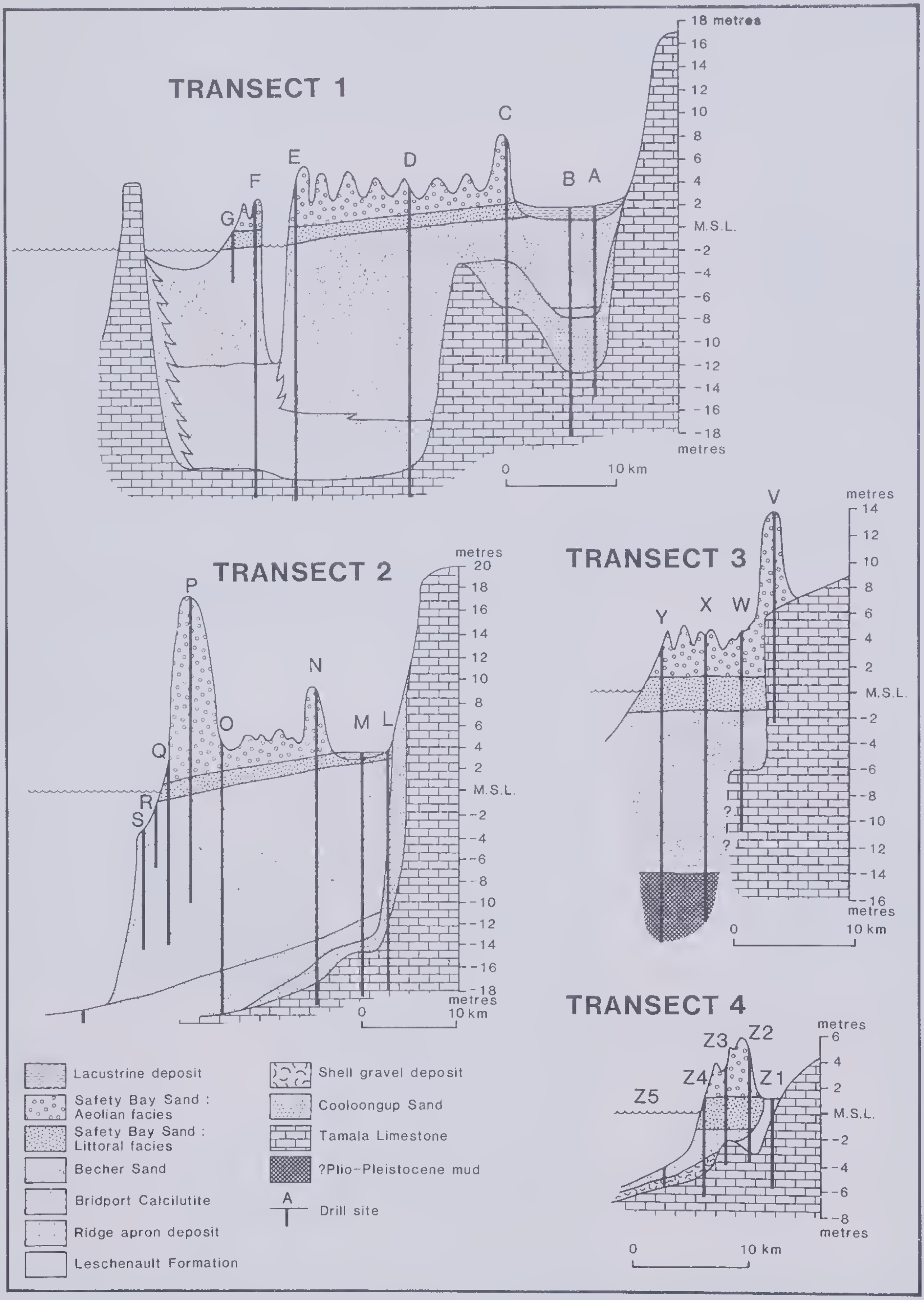

Figure 6 Stratigraphic profiles along 4 east-west transects. Location of transects and drill sites are shown in Figure 3.

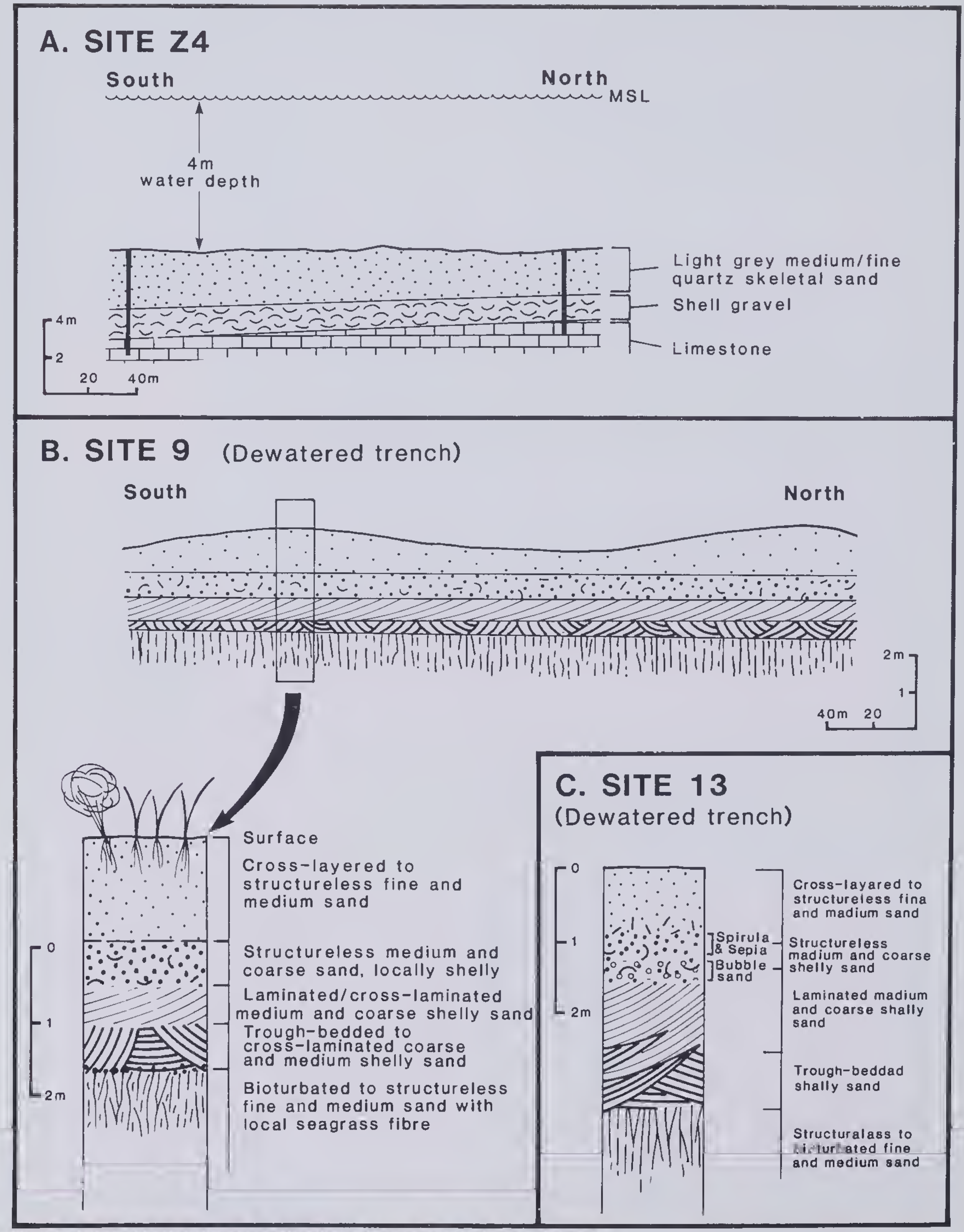
A. SITE Z4
South
North
MSL
4m
water depth
Light grey medium/fine quartz skeletal sand
Shell gravel
Limestone
4m
2
20
40m
B. SITE 9 (Dewatered trench)
South
North
2m
1
40m
20
Surface
Cross-layered to structureless fine and medium sand
Structureless medium and coarse sand, locally shelly
Laminated/cross-laminated medium and coarse shelly sand
Trough-bedded to cross-laminated coarse and medium shelly sand
Bioturbated to structureless fine and medium sand with local seagrass fibre
0
1
2m
C. SITE 13
(Dewatered trench)
0
1
2m
Spirula & Sepia
Bubble sand
Cross-layared to structureless fina and madium sand
Structureless madium and coarse shelly sand
Laminated madium and coarse shally sand
Trough-beddad shally sand
Structuralass to bioturbated fine and medium sand

Figure 7 Details of local stratigraphy at selected sites. Location of sites shown on Figure 3.

sedimentation in this area; the rate of vertical accretion of the sequences; the age structure of the accretionary plain and the development of its geomorphic features; and the history of sealevel during the Holocene. Most of the ages returned from the samples were consistent within the context of their stratigraphic and geographic setting. However, some dates, particularly from peaty wetlands, were anomalous. These will be described and discussed in a future study (Semeniuk *et al.* in prep).

Table 2

Description of Material used in Radiocarbon Dating

Radio-carbon sample site no. Fig.3)	Sample no. this paper	Field no.*	Labor-atory no.	Stratigraphic setting	Rationale for sample	Height (m) of SL indicator if applic able	Sample type**	Age in C14 yrs not C13 corrected	Age in C14 yrs BP C13 corrected	dC13/dC12 (o/oo)
1	1	VCSRG29	GX12028	North shore lake Cooloongup; shelly layer in top of Becher sand	Age of top marine sands	-	Donax	5 395	5 800 ± 305	0.9
2	2-1	VCSRG25	GX12024	West shore lake Cooloongup; shelly beach layer	Age of beach horizon	not determined	Donax & Donacilla	6 075	6 470 ± 375	0.3
	2-2	VCSRG30	GX12029	West shore lake Cooloongup; shell at base of Holocene sequences contact between Becher Sand and Cooloongup Sand	Age of base of the Holocene sequence	-		7 235	7 670 ± 360	1.2
3	3	SH-22	GX11587	Shelly beach layer	Age of beach horizon	+2.4	Donax	5 295	5 700 ± 190	1.0
4	4	SH-10	1-11-978	Shelly beach layer	Age of beach horizon	+2.4	Donax	5 660 ± 110	-	-
5	5	SH-11	1-11-979	Shelly beach layer	Age of beach horizon	+ 1.9	Donax	5 440 ± 110	-	-
6	6	VCSRG24	GX12023	Shelly beach layer	Age of beach horizon	+1.5	Donax	3 670	4 080 ± 250	1.1
7	7-1	VCSRG23	GX12022	Shelly beach layer	Age of beach horizon	+0.5	Donax	2 340	2 760 ± 220	1.9
	7-2	RW15-16	GX12904	Shelly horizon contact between base Becher Sand and Bridport Calcilutite	Age of encroachment of Becher Sand seagrass bank	-	Seagrass gastropod fauna	2 774	3 210 ± 145	2.8
	7-3	RW22-23	GX12903	Shelly horizon at base of Bridport Calcilutite	Age of base of Holocene sequence	-	Pecten shells	6 120	6 535 ± 225	1.5
8	8	SH-21	GX11586	Shelly beach layer	Age of beach horizon	+0.95	Donax	3 892 ± 245	-	1.5
9	9	SH-20	GX11585	Shelly beach layer	Age of beach horizon	+0.7	Donax	2 224 ± 135	-	2.0
10	10	SH-14	1-12-362	Shelly beach layer	Age of beach horizon	+0.7	Donax	2 790 ± 90	-	0.4
11	11	SH-12	1-11-980	Shelly beach layer	Age of beach horizon	not determined	Donax	2 890 ± 85		-
12	12	VCSRG27	GX12026	Shelly beach layer	Age of beach horizon	+2.6	Donax	6 645	7 040 ± 390	0.3

Table 2 Description of Material used in Radiocarbon Dating .... cont.

Radio-carbon sample site no. Fig.3)	Sample no. this paper	Field no.*	Labor-atory no.	Stratigraphic setting	Rationale for sample	Height (m) of SL indicator if applic able	Sample type**	Age in C14 yrs not C13 corrected	Age in C14 yrs BP C13 corrected	dC13/dC12 (o/oo)
13	13-1	SH-9	1-11-977	Shelly beach layer	Age of beach horizon	+2.5	*Donax*	6 380 ± 115	-	
	13-2	VCSRG26	GX12025	Upper level of Becher Sand	Age of Becher Sand upper level	-	Seagrass peat	7 395	7 560 ± 360	-14.6
	13-3	WALY16-17	GX12906	Base of the Holocene -estuarine shell	Age of the base of the Holocene sequence	-	*Katelysia*	7 980	8 365 ± 375	-0.6
14	14-1	VCSRG28	GX12027	Shelly beach layer	Age of beach horizon	+2.6	*Donax*	6 440	6 825 ± 495	-0.4
	14-2	WALY.W. 14-15	GX12905	Mid Becher Sand	Age of Becher Sand	-	*Donax*	7 510	7 920 ± 105	1.3
15	15-1	HR5-1	GX11882	Shelly beach layer	Age of beach horizon	+1.0	*Donax*	2 930	3 340 ± 215	1.8
	15-2	HR5-3	GX11883	Becher Sand 6m below AHD	Age of Becher Sand	-	*Donax*	3 035	3 445 ± 220	1.2
	15-3	HR5-6	GX11885	Becher Sand 14m below AHD	Age of Becher Sand	-	*Donax*	3 220	3 630 ± 225	1.2
16	16-1	HR4-4	GX11879	Becher Sand 1.5m below AHD	Age of Becher Sand	-	*Donax*	1 655	2 070 ± 210	1.8
	16-2	HR4-8	GX11881	Becher Sand 11 m below AHD	Age of Becher Sand	-	*Donax*	2 295	2 705 ± 210	1.3
17	17-1	HR3-1	GX11872	Shelly beach layer	Age of beach horizon	0.0	*Donax*	1 010	1 425 ± 150	1.7
	17-2	HR3-2	GX11873	Becher Sand 2 m below AHD	Age of Becher Sand	-	*Donax*	1 230	1 655 ± 160	2.2
	17-3	HR3-3	GX11874	Becher Sand 4.5 m below AHD	Age of Becher Sand	-	*Donax*	1 400	1 815 ± 160	1.6
	17-4	HR3-6	GX11876	Becher Sand 11 m below AHD	Age of Becher Sand	-	*Donax*	2 080	2 485 ± 205	0.9
	17-5	HR3-8	GX12908	Becher Sand 16m below AHD	Age of Becher Sand	-	Seagrass gastropods & bivalves	2 145	2 550 ± 160	0.8
18	18-1	HR2-1	GX11869	Surface Becher Sand	Age of Becher Sand	-	*Glycymeris* & *Mactra*	modern	modern	1.8
	18-2	HR2-3	GX11870	2 m below surface	Age of Becher Sand	-	Seagrass gastropods	670	1 085 ± 185	1.6
	18-3	HR2-4	GX11871	3 m below surface	Age of Becher Sand	-	Seagrass gastropods	985	1 420 ± 190	3.0

Table 2 Description of Material used in Radiocarbon Dating .... cont.

Radio-carbon sample site no. Fig.3)	Sample no. this paper	Field no.*	Labor-atory no.	Stratigraphic setting	Rationale for sample	Height (m) of SL indicator if applicable	Sample type**	Age in C14 yrs not C13 corrected	Age in C14 yrs BP C13 corrected	dC13/dC12 (o/oo)
19	19-1	HR1-1	GX11866	Surface Becher Sand	Age of Becher Sand	-	*Glycymeris*	modern	modern	1.6
	19-2	HR1-3	GX11867	Beach sand 2 m below surface	Age of Becher Sand	-	Seagrass gastropods	150	565 ± 170	1.5
	19-3	HR1-5	GX11868	Beach sand 5 m below surface	Age of Becher Sand	-	Seagrass gastropods	160	575 ± 170	1.5
	19-4	HR1-9	GX12907	Beach sand 8.5 m below surface	Age of Becher Sand	-	Seagrass gastropod fauna & bivalves	990	1415 ± 145	2.3
20	20	SH-8	1-11-964	Shelly beach layer	Age of beach horizon	+1.6	*Donax*	4 180 ± 105		0.41
	20R	SH-8R	1-12-557	Shelly beach layer	Age of beach horizon	+1.6	*Donax*	4 450 ± 90		-
21	21	SH-5	1-11-777	Shelly beach layer	Age of beach horizon	+1.75	*Donax*	4 745 ± 95		-
22	22	SH-4	1-11-776	Shelly beach layer	Age of beach horizon	not determined	*Donax*	3 525 ± 95		-
23	23	SH-2	1-11-774	Shelly beach layer	Age of beach horizon	+0.3	*Donax*	1 720 ± 80.		-
24	24	SH-3	1-11-775	Shelly beach layer	Age of beach horizon	+0.9	*Donax*	3 495 ± 95		-
25	25	SH-1	1-11-773	Shelly beach layer	Age of beach horizon	+0.0	*Donax*	600 ± 75		-
26	26	SH-6	1-11-962	Shelly beach layer	Age of beach horizon	+0.0	*Donax*	375 ± 75		0.74
27	27	SH-7	1-11-963	Shelly beach layer	Age of beach horizon	+0.0	*Donax*	contemporary		0.46
28	28	SiB3:5-6	GX12628	Shelly beach layer	Age of beach horizon	+1.0	*Donax*	2 285	2 720 ± 185	1.3
29	29	SiB2:6-8	GX12627	Shelly beach layer	Age of beach horizon	+0.0	*Donax*	1 450	1 880 ± 150	1.1
30	30	SiB1:3-4	GX12626	Shelly beach layer	Age of beach horizon	+0.0	*Donax*	205	630 ± 175	0.6
31	31	SSRO (NMB)	GX12622	Shelly estuarine mud	Age of estuarine sand flat	+2.2	*Katelysia* and *Sanguinolaria*	6 535	6 910 ± 235	-2.1
32	32	SSR1:7-8	GX12623	Shelly gravel layer at base of Holocene sequence	Age of estuarine conditions	-	*Katelysia* and *Sanguinolaria*	6 675	7 050 ± 115	-2.3

Table 2 Description of Material used in Radiocarbon Dating .... cont.

Radio-carbon sample site no. Fig.3)	Sample no. this paper	Field no.*	Labor-atory no.	Stratigraphic setting	Rationale for sample	Height (m) of SL indicator if applic able	Sample type**	Age in C14 yrs not C13 corrected	Age in C14 yrs BP C13 corrected	dC13/dC12 (o/oo)
33	33-1	SSR3: 8-9	GX12902	Shelly beach layer	Age of beach horizon	+0.5	mixed Donax Glycymeris & Donacilla	3 060	3 475 ± 160	1.6
	33-2	SSR3: 10-11; Est	GX12625 sequence	Estuarine fauna over-lying unconformity	Age of estuarine conditions	-	Katelysia Sanguinolaria	1 735	2 170 ± 205	1.2
	33-3	SSR3: 10-11; R.Sh.	GX12624	Rocky shore fauna on unconformity on limestone	Age of marine rocky pavement	-	Ninella, chamiids	2 520	2 960 ± 250	1.6
34	34-1	MH3 1.5m	GX12682	Seagrass fauna in shell gravel 1.5 m below surface	Age of seagrass bank deposits	-	Mactra	3 240	3 645 ± 160	0.7
	34-2	MH3 1.5 m	GX12683	Rocky shore fauna in shell gravel 1.5 m below surface	Age of rocky shore deposits	-	Ninella & chamiids	5 335	5760 ± 335	2.0
	34-3	MH3 1.5 m	GX12685	Beach fauna in shell gravel 1.5m below surface	Age of beach deposit	-	Glycymeris & chamiids	5 850	6 305 ± 205	2.6
	34-4	MH3 1.5 m	GX12686	Estuarine fauna in shell gravel 1.5 m below surface	Age of estuarine deposits	-	Katelysia	6 540	6 950 ± 230	1.1
	34-5	MH3 1.5 m	GX12681	Rocky shore fauna in shell gravel 1.5 m below surface	Age of rocky shore deposits	-	Oyster	7 025	7 420 ± 260	0.5

Footnotes:

* GX numbers: Kreuger Geochron Laboratories

1-11-98 numbers: Teledyne Laboratories

** Sample type Type of sample used and brief description of sample preparation

1. Donax; processing carried out as outlined by Woods & Searle (1983) and Searle & Woods (1986).

2. Bivalves such as Glycymeris and Mactra from seagrass bank assemblages; samples chosen for processing were clean, fresh, lustreous specimens lacking in adhering cements and dull patches.

3. Gastropods from seagrass bank assemblages usually large specimens of Prothalotia and allies; tip of spire of the large specimens of the gastropods was removed by pliers and the hollow body whorl was flushed clean of any adhering sediment to provide clean samples, (without sediment packed in body whorls) for radiocarbon analyses.

4. Seagrass peat; sample was oven dried and wrapped in aluminium foil for despatching.

As outlined in Woods & Searle (1983) and Gillespie & Polach (1979), it is necessary to consider both C13 corrections and the reservoir effects when reporting radiocarbon dates. Gillespie & Polach (1979) have considered the reservoir effects on dating Australian marine shells, and included material from southwest Australia in their study; they determined a mean correction value of 450±35 years, to be subtracted from any uncorrected date. Isotopic fractionation was determined for most of the samples used in this study (Table 2). Most results were close to the expected value of 0±1%, d13C/d12C predicted by Stuiver & Polach (1977) for marine carbonate, and therefore an age correction factor of 410±70 years is applicable. This value, when added to a radiocarbon age, approximately cancels the correction for the reservoir effect. Because the major correction factors cancel when dating Australian marine shells, then the reported dates in ears BP can be used directly.

Initiation of Holocene sedimentation

The results from radiocarbon dating confirm that the Bridport Calcilutite, the Becher Sand and the Safety Bay Sand are wholly Holocene (Table 2). The Holocene record begins at about 8000 C14 yrs BP. Age determinations at site M (Fig. 8) adjacent to the Spearwood ridge, the most eastern sampling sites, indicate that the post-glacial marine transgression had reached this shoreline by 7980 C14 yrs BP and that beach conditions were established by 6645 C14 yrs BP.

Vertical accretion rates

Radiocarbon dates from the basin, bank and beach units provide a 3-dimensional picture of the age structure of the Holocene sediments of the Rockingham-Becher Plain. Ages from sites A, C, L, M and N (Fig. 8) indicate that between about 8000 and 6500 yrs BP, the sediments under the Rockingham Bank shoaled from deepwater to within about 2m of the former sealevel. Ages from sites 0, P, Q, W, X and Y indicate that the Becher Bank is a younger sedimentary accumulation.

Age structure of plain

Beachridges mark successive shoreline positions and in effect represent isochrons. When combined with the radiocarbon data, they enable the history of shoreline progradation to be determined. Radiocarbon ages of the shells from the beach facies at various sites indicate that the age structure of the plain is reasonably internally con-

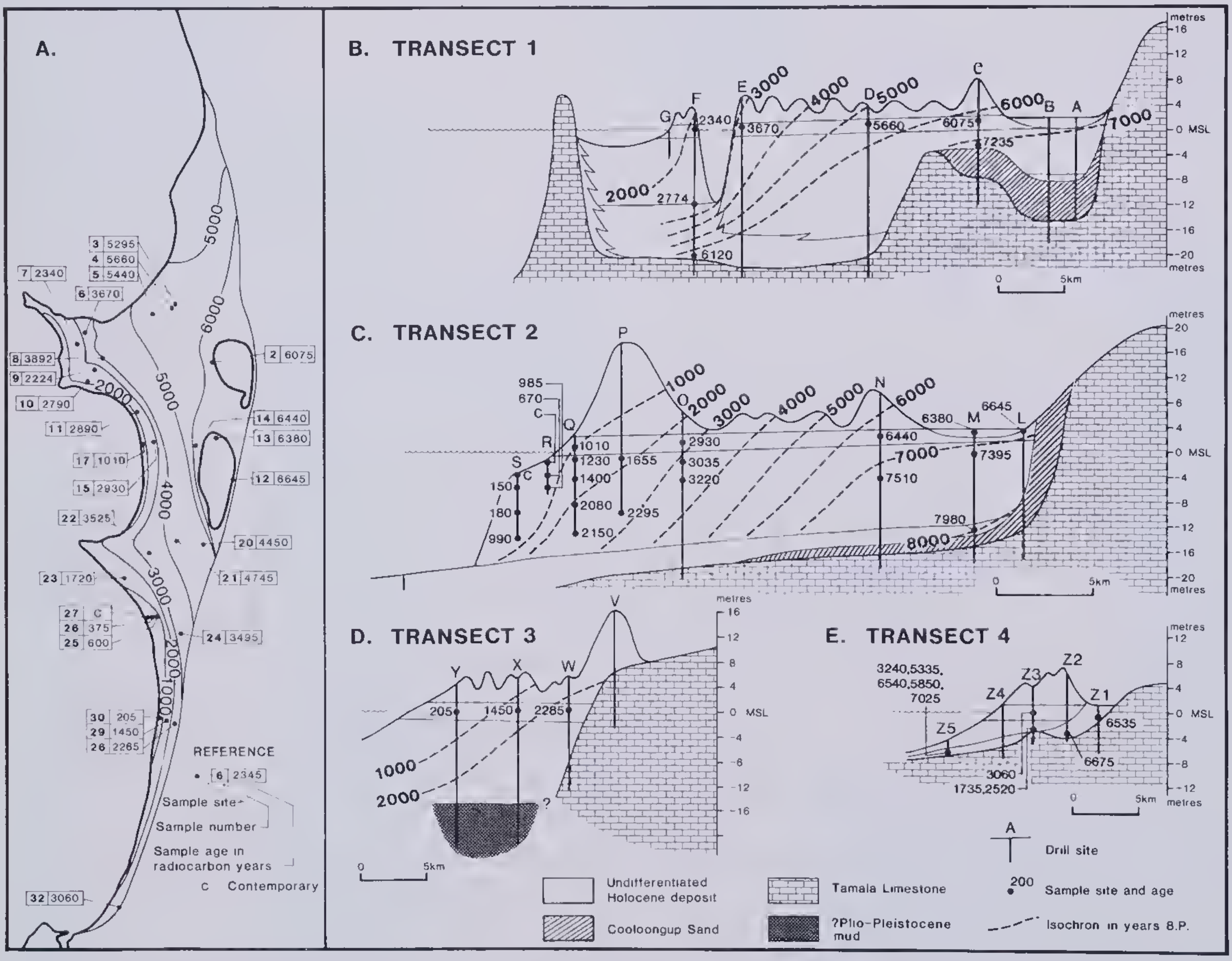

Figure 8 Age structure of the beachridge plain. A Plan view showing isochrons in 1000's of years, determined by dating shell from beach horizons (see Table 2); locations of sample sites shown in Figure 3. B Cross sections through the 4 transects showing interpreted isochrons based on radiocarbon results; sample sites, sample depths and radiocarbon ages are shown on cross sections; Table 2 describes sample type in more detail.

sistent. The beach facies ranges in age from about c 6600 C14 yrs adjacent to the Spearwood Ridge to contemporary along parts of the modern shore (Fig. 8).

Age of shell gravel

The shell gravel in the nearshore submarine environment north of Mandurah and beneath the Safety Bay Sand at San Remo provided a range of ages for the various shell components (samples 32, 33-2, 33-3, 34-1, 34-2, 34-3, 34-4, 34-5). Rocky shore shells, indicating open marine conditions, gave ages of 2500, 5335 and 7025 C14 yrs BP; estuarine shells indicate that estuarine conditions existed at the site at various times between 6540 and 1700 C14 yrs BP; and seagrass fauna and beach fauna gave ages of 3240 and 1900 C14 yrs BP.

Sealevel history

Beneath the prograded beachridge plains there is a distinct horizontal stratigraphy with beachridge/dune sediments overlying beach sediments which, in turn, overlie bank sediments (Figs 6 & 7). Contemporary beach (swash zone) sediment, can be related to MSL, and former beach sediments now buried inland provide an indication of the position of former sealevel. In addition, the contact between the Safety Bay Sand and Becher Sand represents a stratigraphic interface between sediments of the beach and bank facies and also is useful as an indicator of relative MSL (Searle & Woods 1986). The modern contact between Safety Bay Sand and Becher Sand is approximately 0.5-1.5 m below MSL in protected embayments (in Cockburn Sound and Warnbro Sound), and up to 2.0 m below MSL along more exposed coasts; this interface never forms above MSL.

The elevations of former sealevel indicators were determined mostly in a 10 km long continuous trench (the Cape Peron pipeline route), or dewatered pits (Fig. 3), or from precisely recovered drill core material (Fig. 3). The middle of swash zone sediments in the sequence was considered to be the best indicator of former sealevel. In some shallower pits (where deep excavations were not possible because of groundwater problems), only the backshore sediments were exposed. However, the elevation of former MSL was interpreted relative to the top of the backshore sediments using the average thickness difference (1.2 m) between sediments of the mid swash and the top of the backshore shown at the present coast and in the deeper pits.

In the stratigraphic sequence beneath the beachridge plain the sheet of swash zone sediments rises gradually to reach an elevation of +2.5 m above MSL about l0km inland adjacent to the Spearwood Ridge, implying a relative MSL of about +2.5 m earlier in the Holocene i.e. 6645 C14 yrs BP. The elevation of the top of the bank sands, (*i.e.* the interface between beach and bank sediments), beneath the plain also rises gradually to reach an elevation of between +1.2 to 1.8 m inland, confirming a relative sealevel high in the order of up to +2.5 m above MSL earlier in the Holocene.

The dating of sealevel indicators at various sites enables a reconstruction of sealevel history for the interval of the Holocene *c* 8 000 C14 yrs BP to the present (Searle & Woods 1986, Semeniuk & Searle 1986b). The data pertaining to sealevel indicators, their ages and their stratigraphic elevation or position relative to present MSL are presented in Table 2. The elevation of the mean sealevel indicators and their radiocarbon ages are shown in Figure 9.

A sealevel history curve derived from these data shows that the Holocene sealevel on this coast reached an elevation of at least +2.5 m some 7000 C14 yrs BP, and then gradually declined, reaching the present level shortly after 1000 yrs BP (Fig. 9). Sealevel subsequently has remained close to present datum. Semeniuk & Searle (1986b), however, also pointed out potential small scale sealevel oscillations in the interval between 5000-4000 C14 yrs BP. This study has not excluded the possibility of such small scale fluctuations in that time interval.

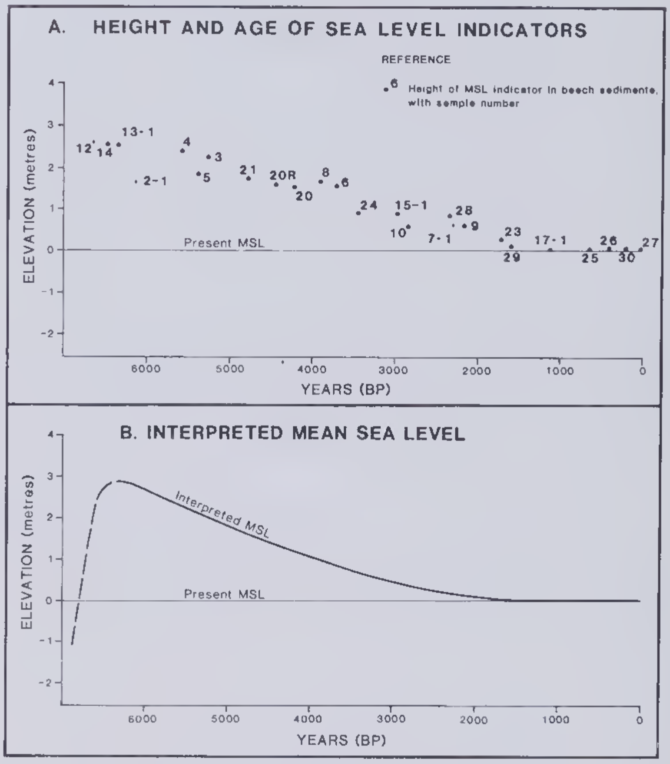

Figure 9 A Graph showing elevation of sealevel indicators and radiocarbon age for a variety of shell samples from beach horizons.

B Interpreted mean sealevel history for the past 7000 yrs.

The reconstruction of local sealevel history in this area is in general agreement with previous local data (Hassell & Kneebone 1960, Fairbridge 1961, Playford & Leech 1977) in that there is evidence for a higher relative MSL during the Holocene, but, as discussed by Searle & Woods (1986), no evidence was found for the ±3 m oscillations proposed by Fairbridge (1961). Further, more detailed investigations are still required to assess the possibility of smaller (±1 m) oscillations over the entire interval of 7000 C14 yrs BP to the present.

The sealevel history of this study differs from interpretations obtained from some other localities in the Northern Hemisphere and eastern Australia which do not show a significant rise in level above present datum, and elsewhere along the Western Australian coast (Jelgersma 1966, Curray 1960, Shepard 1963, Milliman & Emery 1968, Morner 1976, Thom *et al.* 1969, Thom & Chappell 1975, Semeniuk & Searle 1986a). Searle & Woods (1986) originally suggested that there were two possible explanations for the apparent discrepancy: hydro-isostatic responses (Chappell 1974, Clark *et al.* 1978) or local tectonism (Playford & Leech 1977, Semeniuk & Searle 1986b). The results of this study would appear to be consistent with hydro-isostatic displacement, the sense and magnitude of which compare favourably with results reported by Chappell *et al.* (1982) and Chappell (1983) for northeastern Australia. However, local tectonism seems more likely to explain the variability in sealevel record. Playford & Leech (1977) noted that there has been up to 300 m of uplift of the Yilgarn Block since the Eocene, and suggested local tectonism as one of the causes for the elevated sealevel record on this coast. Semeniuk & Searle (1986b) recently discussed the significance of local tectonism in producing a variable sealevel history within accretionary sequences between Bunbury and Whitfords.

Reconstruction of palaeogeography during the Holocene

Philosophy of approach

The stratigraphy and age structure of the Rockingham-Becher Plain can be used to provide a synthesis of the geomorphic evolution of the system. This section attempts to present a simplified reconstruction of palaeogeography during the Holocene between 8000 C14 yrs BP and the present. The synthesis is based on:

- the stratigraphy and its palaeo-environmental significance: the beach facies of the Safety Bay Sand are littoral zone sediments; the beachridge and dune facies of the Safety Bay Sand are aeolian sediments; the Becher Sand has formed in submarine bank environments, encompassing seagrass, slope, sand wave and sand flat lithotopes; and the Bridport Calcilutite was deposited in protected basins;
- the age structure of the various stratigraphic units, and specifically the beach sediments beneath the plain;
- the assumption that a beachridge line represents a synoptic picture of the shoreline, and that the radiocarbon age of shell material from the beach facies provides an age of the overlying beachridge shoreline;
- a modified interpretation of Searle (1984) for the geomorphic evolution of the coastal system, i.e., islands and reefs of the offshore Pleistocene aeolianite ridges erode and degrade, whereas Holocene banks and beachridge plains are depositional and progradational (Fig. 10).

Searle (1984) concluded that Holocene sediment accretion in this region has been controlled by the interaction of the shelf wave climate with the complex and eroding ridge-and-depression bathymetry, the abundant sources of sediment, and the evolving bank structures. Under the influence of prevailing swell and wind waves, there has been net northward sediment transport along the exposed seaward face of the Garden Island Ridge and mainland Spearwood Ridge. Where the offshore ridge sheltered the mainland shore, longshore transport diminished as the Garden Island ridge gained prominence. As a result the northern littoral drift accumulated in the sheltered area behind the south of Garden Island to form a submarine bank and a series of recurved spits (*ie* a tombolo effect).

The Garden Island Ridge also acted and still functions as a perforate barrier allowing a portion of the incident waves through gaps and passages into the otherwise shel-

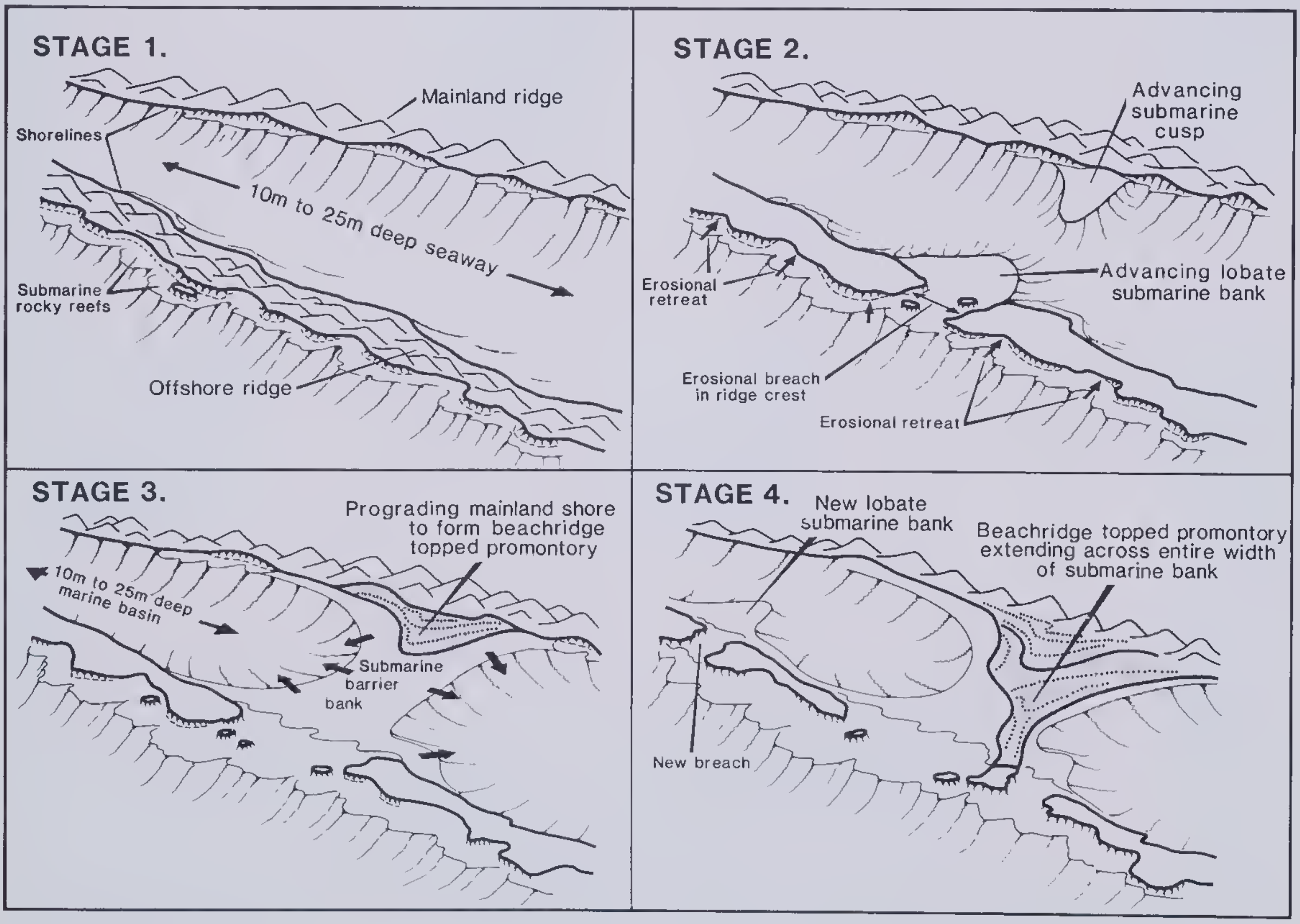
STAGE 1.
Mainland ridge
Shorelines
10m to 25m deep seaway
Submarine rocky reefs
Offshore ridge
STAGE 2.
Advancing submarine cusp
Erosional retreat
Advancing lobate submarine bank
Erosional breach in ridge crest
Erosional retreat
STAGE 3.
Prograding mainland shore to form beachridge topped promontory
10m to 25m deep marine basin
Submarine barrier bank
STAGE 4.
New lobate submarine bank
Beachridge topped promontory extending across entire width of submarine bank
New breach

Figure 10 Stages in the geomorphic evolution of the coastal systems (revised and modified after Searle 1984).

tered depressions. Waves passing through breaches in the ridge divert sediment from the transport pathway on the seaward side of the ridge transporting it eastward into the adjacent depression to form lobate submarine banks. Onshore Holocene sediment transport has been largely influenced by these loci of transmitted wave energy to form well defined submarine banks.

Refraction over the banks causes convergence of waves that have passed through the ridge crest toward the central axis of the banks. Thus sediment impelled shoreward is contained within the bank axis. The convergence of waves also causes a local accumulation of littoral sediment on the mainland shore. Where the submarine bank lobe has accreted to the extent that it perturbates the swell wave pattern and disrupts the longshore transport pattern on the mainland coast, it causes the mainland to accrete as a large sandy submarine "cusp" toward the advancing bank. When the bank and cusp meet, progradation of the mainland shore across the submarine bank surface is initiated and is centred on the bank-cusp axis. As a result banks become capped with an extensive cuspate beachridge plain. In contrast, the coastline *between* adjacent banks progrades much more slowly. Coincident with bank accretion there is continuing erosion and widening of breaches in the Garden Island Ridge culminating in the reduction of the island chain to a series of submerged reef lines.

The palaeogeographic reconstruction presented in this paper thus incorporates the large scale evolution of banks and concommittant erosion of ridges. As such the paper provides an alternative to palaeogeographic reconstruction of the Holocene evolution as presented by Churchill (1959) and subsequent authors (e.g. Seddon 1972).

In the nearshore submarine area north of Mandurah the mixed lag of shells and their ages indicate that estuarine conditions existed locally up to 3000 C14 yrs BP. The estuarine deposits would have been protected by a spit or barrier (similar to the modern Wonnerup Inlet, Geographe Bay). The barrier was probably flanked to seaward by a beach and bank facies. The entire sequence of estuary, barrier spit and bank sediments have since been eroded leaving a gravel lag of mixed estuarine, bank, beach and rocky pavement shells.

Palaeogeographic reconstructions

For convenience, the reconstruction of Holocene palaeo-geography is described in 5 stages (Fig. 11):

Stage 1:	pre 8000 C14 yrs BP
Stage 2:	8000-6000 C14 yrs BP
Stage 3:	6000-4000 C14 yrs BP
Stage 4:	4000-2000 C14 yrs BP
Stage 5:	2000 C14 yrs BP to present

Stage 1:pre 8000 C14 yrs BP: During the last glaciation around 20000 yrs BP the limestone ridge-and-depression landscape between Mandurah and Fremantle was exposed with the sea situated approximately some 50 km to the west along the 100 m contour. The local terrain consisted of two major ridges standing some 40-60 m above the floor of an elongate valley which extended northward from the Peel-Harvey valley to open onto a flat plain near Fremantle. Apart from several low and discontinuous ridges, the valley was featureless. It is possible that at this time the Harvey, Murray and Serpentine rivers all discharged into the southern part of the valley before flowing northwards to coalesce with the Swan River near Fremantle. By about 18000 yrs BP the ice age ended and world sealevel started to rise. The sea first entered the valley around 8500 C14 yrs BP resulting in local deposition of estuarine deposits in the deeper depressions.

Stage 2:8000-6000 C14 yrs BP: Between the period 8000-6000 C14 yrs BP when sealevel rose to near its present level the ancestral elongate valley was flooded to a depth of some 20 m, to form a continuous waterway, the Warnbro-Cockburn Depression. The mainland shore, comprised of limestone rocky shores, pocket beaches and localised parabolic dunes, was situated along the western margin of the Spearwood Ridge. The Garden Island Ridge was mostly a continuous elongate island with only one major opening to the south. It is also probable that the Five-Fathom-Bank Ridge was almost totally inundated.

Marine erosion of the weakly lithified Garden Island Ridge resulted in a breach developing near Rockingham which allowed sediment supplied from the eroding breach and from the western side of the ridge to be transported into the depression behind. The transported sediment was confined to loci of wave convergence, which extended eastward, and a discrete east-west bank began to form. Concurrently, the mainland shore was subject to normal littoral processes which transported sand along the coast from the south. Where the mainland topography was low, sand was mobilised inland to form transgressive parabolic dunes perched on the Spearwood Ridge.

The majority of sediment impelled north by littoral drift, however, progressively accumulated under the combined effect of the shelter of the Garden Island Ridge and the influence of the now inundated lower limestone ridge to form a bank (the incipient Rockingham Bank) topped by a series of recurved spits. These spits eventually enclosed a northfacing embayment. While the embayment was open to the sea its southern part became filled with seagrass bank sediments that were in part covered subsequently by the spits. By 6500 C14 yrs BP the spits linked with the Spearwood Ridge in the north thereby isolating the embayment from the sea, the northern half remaining an unfilled water body some ?10 m deep.

In the Mandurah area a barrier spit-protected estuary developed at the mouth of the Peel-Harvey exchange channel. In response to the nett northerly littoral drift and the protection of Murray reefs and Halls Head, the estuarine-spit complex probably was oriented parallel to the coast extending from Mandurah toward the north.

Stage 3:6000-4000 C14 yrs BP: During this period breakdown of the Garden Island Ridge and partitioning of the Warnbro-Cockburn Depression into discrete basins continued. Sand transported onshore and alongshore contributed to the rapid growth of the Rockingham Bank and the subaerial beachridge plain, which by 4000 BP had extended halfway across the depression. Another major breach in the Garden Island Ridge was developed also during this period and sands were transported through the breach into the depression behind to initiate and contribute to the formation of the Becher Bank. By 4000 BP the Becher Bank had sufficient elevation to influence the shape of the shoreline behind.

The barrier spit-protected estuary was still located to the north of the Peel-Harvey estuary exchange channel.

Stage 4:4000 -2000 C14 yrs BP: During this period break-down of the Garden Island Ridge, growth of Becher Bank, and progradation of beachridge plains over the axes of both Becher and Rockingham banks continued. Sand transported onshore and alongshore contributed to growth of Becher Bank to the extent that the growth pattern of the entire Rockingham-Becher Plain began to re-

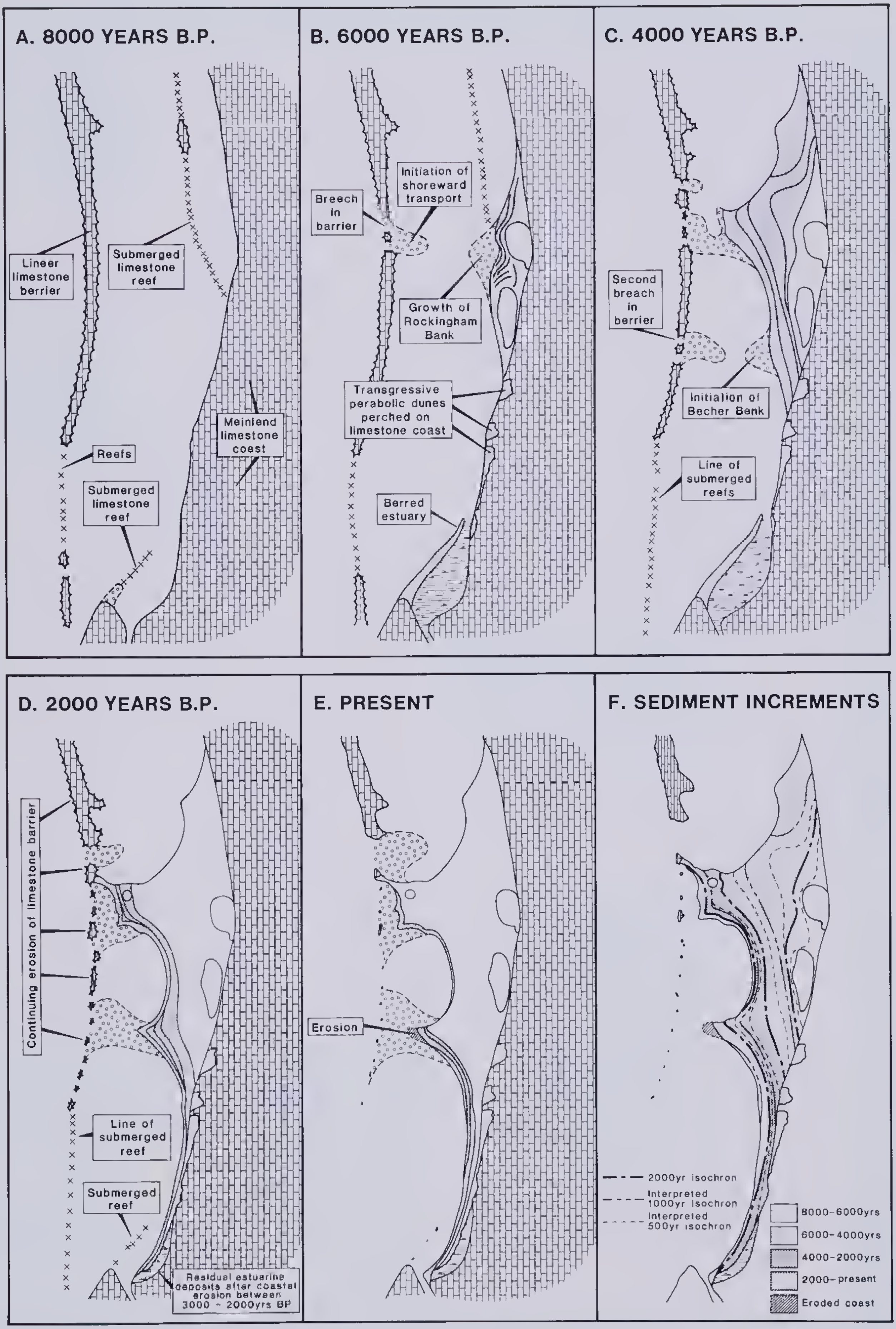

Figure 11 The geomorphic history and coastal changes in the study area over the past 8000 yrs in 2000-yr intervals; F shows the asymmetric incremental nature of sediment accretion.

flect the presence of both banks. The pattern of growth of the Rockingham Plain became complex as it neared the Garden Island Ridge, with smaller scale tombolos and spits developing behind the remnants of the ridge and the broken chain of submerged reefs to the west. By *c* 2 500 C14 yrs BP Rockingham Plain joined with the Garden Island Ridge linking Pt Peron with the mainland and effectively separating Warnbro Sound from Cockburn Sound. Subsequently, Lake Richmond was isolated from Cockburn Sound by the advancing Rockingham Point which linked with the older ridges to the west. Towards the end of this period Becher Bank had developed to the stage where rapid advance of the subaerial Becher plain was possible. This consumed most of the available sand arriving from the south, effectively depleting the supply to beaches to the north. Consequently while Becher Point prograded rapidly, the shores to the north remained static or prograded slowly.

Up to 3000 C14 yrs BP the barrier spit-protected estuary was still located to the north of the Peel-Harvey estuary exchange channel. Thereafter the entire barrier-estuary sequence was eroded to leave a ribbon-shaped shell gravel lag deposit to be buried later by nearshore shelf sand and onshore aeolian sand.

Stage 5:2000 C14 yrs BP to Present: During the last 2000 yrs breakdown of the Garden Island Ridge and growth of the Becher Plain has continued. The growth of the Becher Bank and plain combined to deplete the supply of sand to the beaches to the north. Consequently some beaches north of Warnbro Sound have undergone minor erosion whilst the shore of Warnbro Sound itself has advanced more slowly. The presence of truncated ridge trends south of Becher Point suggests that Becher Pt itself ceased advancing some time within the last 500 years with resulting erosion and realignment of the point. The final coastal configuration and geography as a result of the coastal evolution and the incremental sediment additions for each 2000 yr interval are shown in Fig. 11. The incremental sediment additions indicate that supply of sediment, to a large extent, has been from the south possibly from the eroding Leschenault-Preston Sector as suggested by Semeniuk & Meagher (1981).

Discussion

The natural history features of the Rockingham-Becher Plain are significant in Western Australia and also have worldwide importance for a number of reasons. Firstly, the Rockingham-Becher Plain comprises the largest accumulation of Holocene sand in the region of the inner Rottnest Shelf coast, with *c* 5 x 10^9 m^3 of sediment stored in system. In contrast, elsewhere in the region, the Leschenault-Preston Sector contains *c* 3 x 10^9 m^3 of sediment, and Geographe Bay contains *c* 0.5 x 10^9 m^3 of sediment. As a consequence of the large amount of stored sediment, the Holocene sand deposit of the Rockingham-Becher Plain potentially contains a wealth of natural history information. For instance, the Holocene deposits preserve an interesting stratigraphy and history of sedimentation.

The sedimentary system of the Rockingham-Becher Plain is relatively simple and can be classified as a carbonate complex, akin to the Shark Bay seagrass sedimentary complexes, notwithstanding that in the Rockingham-Becher area there also is a significant quartz content in the sediment. The stratigraphy of the area also is relatively simple, consisting essentially of three main units accumulated in superposition, and each representing a distinct environment of deposition. The style of sedimentation and the coastal history of the area, in that it is an example of Holocene sedimentation in a bathymetrically complex coastal zone, contrasts with that of the other sectors of the inner Rottnest Shelf (Searle & Semeniuk 1985) and, for that matter, areas such as Shark Bay (Logan & Cebulski 1970) or the tropical macrotidal coast of northwestern Australia (Semeniuk 1986b). Consequently, the Rockingham-Becher Plain area is significant in that the sedimentologic-stratigraphic model derived from this area provides a case book example of worldwide importance of Holocene sedimentation and stratigraphic evolution.

Additionally, a range of natural features in the area provide a unique opportunity to enable reconstruction of sealevel history and geomorphic evolution of the plain. These features include the abundance of Holocene and contemporary skeletal material available for radiocarbon dating in the carbonate-rich sediment, the specific sealevel indicators as preserved in the stratigraphic sequence, the microtidal setting, and the distinctive parallel beachridge coastal geomorphology that results from shoreline progradation. In contrast to many other sedimentologic settings elsewhere in the world, the microtidal setting and facies types of the Rockingham-Becher area has resulted in a simple and concise layered stratigraphy. Again, in contrast to other sequences elsewhere, the abundant shell material in the Rockingham-Becher deposits enables shells of various phylogenetic groups to be rigorously selected for radiocarbon analysis, and allows for dating from a selected stratigraphic interval. Other sequences elsewhere in the world or in eastern and southern Australia, while they may exhibit distinct beachridge trends do not necessarily contain abundant shells for radiocarbon processing; those that are composed of abundant shells and carbonate sediment do not necessarily exhibit the definitive and extensive coastal beachridge patterns or depositional environments present in this area. The factors of abundant shell material available for C14 analysis, the simple stratigraphy, and the definitive geomorphic trends are all present *in conjunction* in this study area.

Another important feature is that beachridge plains described worldwide frequently contain a sequence of ridges that reflect changes in depositional style during the period 7000 yrs BP to present. The Rockingham-Becher Plain on the other hand reflects a consistent depositional style throughout the latter period of the Holocene. As a consequence the geomorphology and stratigraphy of the Rockingham-Becher Plain assumes a national to worldwide significance, and it is suggested here that the area can be used as a model for coastal evolution for global geomorphic, sedimentologic and stratigraphic studies.

In addition, because it records a depositional history from 7000 C14 yrs to the present, and contains a preserved stratigraphy and geomorphology throughout this interval of the Holocene, the Rockingham-Becher Plain also assumes importance as a potential resource to investigate long term climate changes and cyclic sedimentation patterns. This has important implications for climatologists attempting to unravel Holocene climate changes over the past 7000 yrs as an index to predicting future climatic trends.

The record of sealevel history preserved in the sequences of the Rockingham-Becher Plain also is important. The Western Australian coast always has been the focus for global interest in sealevel studies because of the pioneering studies of Fairbridge (1961) centred on Rottnest Island and Point Peron. Although the accretionary sedimentary record provides evidence on sealevel history that differs with that derived from rocky shores, the record preserved in the stratigraphy under the beachridge plains is still of global importance. This sealevel history that has been documented as a standard example of sealevel response for this part of the continent and, in conjunction with the evidence from elsewhere in southwestern Australia, provides an important addition to a global to regional understanding of Holocene sealevel history.

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A census of the larger fungi of Western Australia Part II

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Abstract

A further 205 taxa of larger fungi are added to the 299 listed in Part I, published in 1982 (Hilton, J R Soc W Aust 65: 1-15). New species and varieties based on collections within the State since 1982 are included, numbering 15. In addition, 6 revisions of names used in Part I are given and one Drummond species and one Preiss species are recorded as re-collected.

Introduction

The census which follows includes some 200 species and varieties of the larger fungi of Western Australia based on citable herbarium specimens collected or located since Part I was published (Hilton 1982). Since Part I was submitted for publication in May 1980 a number of special collections have been made. The International Botanical Congress in August 1981, held at Sydney, brought H Clémençon, E Horak and O K Miller to the State. During 1981 N Bougher (1983) made a special study of the dung coprini, and K Kenneally collected tropical polypores. J Trappe collected subterranean fungi, an area extended by N Malajczuk and his associates at CSIRO, and by G Beaton. R Watling visited in May 1982 and also collaborated with G Kile in elucidating the status of *Armillaria* species. E Horak re-visited the State in 1985.

Arrangement

The classification of Ainsworth, Sparrow & Sussman (1973) has been followed for consistency with Part I, although more modern treatments are available, especially for those put under Hymenogastrales and Tuberales.

Collections which involve the type specimen are indicated by an asterisk (*).

Sub-division Ascomycotina: "Ascomycetes"
(classes omitted)

Order Clavicipitales

Family Clavicipitaceae

Claviceps puspali Stevens & Hall, Bot Gaz 50:462 (1910). Esperance, on *Paspalum dilatatum* (UWA 1014).

Claviceps purpurea (Fr.) Tulasne, Ann Sci Nat Bot III 20:45 (1853). Albany, on *Festuca elatior* var *arundinacea* (UWA 1647).

Cordyceps brittlebankii McLennan & Cookson, Proc R Soc Vic 38:74 (1926). Wanneroo (UWA 671).

Order Helotiales

Family Geoglossaceae

Trichoglossum hirsutum (Persoon: Fr.) Boudier, Hist Class des discomycètes d'Europe 86 (1907). Porongorups (UWA 843).

Family Helotiaceae

Discinella terrestris (Berk. & Br.) Dennis, Kew Bull 13:342 (1958). Bremer Bay (UWA 2238).

Order Pezizales

Family Ascobolaceae

Ascobolus immersus Pers. : Pers., Mycol eur 1:341 (1822). Cannington (UWA 3375). Subject of Univ W Aust Honours dissertation by H K Tan, 1964.

Family Pezizaceae

Peziza violacea Pers., Mycol eur 1:242 (1822). Yanchep (UWA 859), Gleneagle (UWA 2832).

Peziza whitei (Gilkey) Trappe, Mycotaxon 2:112 (1975). Porongorups (UWA 697).

Family Pyronemataceae

Anthracobia muelleri (Berk.) Rifai, Australasian Pezizales p. 141 (1968). Kings Park (UWA 1263), Wanneroo (UWA 1527), Karragullen (UWA 1935).

Cheilymenia coprinaria (Cooke) Boudier, Hist Class Discom Eur 63 (1907). Ludlow (UWA 1033).

Inermisia fusispora (Berk.) Rifai, Australasian Pezizales p 198 (1968). Moore River (UWA 871).

Jafneadelphus asperulus Rifai, Australasian Pezizales p 91 (1968). Dawesville (UWA 2448).

Family Sarcosomataceae

Plectania rhytidia Berk., Hook. f., Fl Nov Zeal 2:200 (1855). Boranup (UWA 2819).

Order Sphaeriales

Daldinia concentrica (Bolton: Fr.) Cesati & de Notaris, Comm Soc Crittogam Ital 1:198 (1963). Porongorups (UWA 683, 877), Mitchell Plateau (UWA 2754).

Hypoxylon fuscum Pers.: Fr., Summa Veg Scand p 384 (1849) Donnelly Mill, on bark of karri (UWA 3436).

Hypoxylon rubiginosum Pers.: Fr., Summa Veg Scand p 384 (1849) Dampier Peninsula (UWA 2779).

Xylaria polymorpha (Pers.) Greville, Flora Edinensis p 355 (1824) Mt Barker (UWA 2853).

Order Tuberales

Family Tuberaceae

Revision: ***Choiromyces aboriginus*** Trappe, Mycotaxon 9:334 (1979). Listed previously as *Elderia arenivaga*.

Clelandia bulundari see ***Mycoclelandia bulundari.***

Revision: *Elderia arenivaga* see ***Choiromyces aboriginus.***

Labyrinthomyces steenisii see ***Labyrinthomyces varius.***

Labyrinthomyces varius (Rodway) Trappe, Mycotaxon 9:321 (1979). Perup River (UWA 1886). Originally described as *Stephensia varia* Rodway, synonymous with *Labyrinthomyces steenisii* Boedijn.

Labyrinthomyces westraliensis Beaton & Malajczuk, Trans Br Mycol Soc 86:503 (1986). Kings Park (MELU*).

Labyrinthomyces westraliensis var ***parvulosporus*** Beaton & Malajczuk, Trans Br Mycol Soc 86:506 (1986). Rottnest I (MELU*).

Mycoclelandia bulundari (Beaton) Trappe & Beaton, Trans Br Mycol Soc 83:535 (1984). Balgo Mission, as *Clelandia bulundari* Beaton (UWA 2427*) (MELU).

Stephensia varia see ***Labyrinthomyces varius.***

Sub-division Basidiomycotina : "Basidiomycetes"
Class Hymenomycetes
Sub-class Phragmobasidiomycetidae
Order Tremellales
Family Tremellaceae

Aporpium caryae (Schw.) Teixeira & Rogers, Mycologia 47:408 (1955). Manjimup (PDD 52472).

Sub-class Holobasidiomycetidae

Order Agaricales

Family Agaricaceae

Agaricus bisporus (Lange) Pilat, Acta Mus nat Prague 7b (1951). Crawley (E) Fremantle (UWA 1478).

Agaricus langei (Möller) Möller, Friesia 4 (1952). As *Psalliota vinacea* Cleland. Gleneagle (UWA 2587) (VPI).

Agaricus placomyces Peck, Ann Rep NY State Mus 29:40 (1878). Northcliffe (Watling 10209) (E).

Agaricus silvaticus Fr., Epicr Syst Myc p 214 (1838). Denmark (UWA 2378) (UWA 2357).

Agaricus silvicola (Vitt.) Peck, Rep NY Mus 36 (1883). S Perth (UWA 1484).

Psalliota vinacea see ***Agaricus langei.***

Family Amanitaceae

Amanita ananaeceps (Berk.) Sacc., Syll Fung 5:18 (1887). Kalamunda, as *Amanita farinacea* (Sacc.) Cleland & Cheel, (E), Pemberton (UWA 1480).

Amanita conicobulbosa Cleland, Trans R Soc S Aust 55:152 (1931). Watling (1975) records a number of collections made in 1974. (E).

Amanita farinacea see ***Amanita anunaeceps.***

Amanita grisea Massee & Rodway, Kew Bull 156 (1901). Nannup Road (Watling 10187) (E), Pemberton (Watling 10215) (E). Gleneagle (UWA 2048) Jandakot (UWA 2057).

Amanita murina Sacc., Syll Fung 9:2 (1891). Dryandra (UWA 1907) Two Peoples Bay (UWA 2665) Mundaring (UWA 2820).

Amanita nauseosa (Wakefield) Reid, Beihefte Nov Hedwig p 25 (1966). Nedlands (UWA 2569).

Amanita ochrophylla (Cooke & Massee) Cleland, Trans R Soc S Aust 48:237 (1924). Donnybrook Sunklands (UWA 2582) (K).

Amanita punctata (Cleland & Cheel) Reid, Aust J Bot Suppl Ser No 8 p 50 (1980). Perup (UWA 3017).

Amanita subalbida Cleland, Trans R Soc S Aust 55:152 (1931). Two Peoples Bay (K) Harvey (UWA 2580).

Limacella illinita (Fr.) Murrill, N Amer Fl 10:40 (1914). Barton's Mill (UWA 2541).

Limacella ochraceolutea P D Orton, Notes R Bot Gdn Edinb 29:105 (1969) Nedlands (UWA 2839).

Family Bolbitiaceae

Agrocybe arenicola (Berk.) Singer, Beih Bot Centralblatt Abt B 56:169 (1936). Kings Park (UWA 1498) Esperance (UWA 1773).

Agrocybe neocoprophila Singer, Lilloa 26:95 (1953), Harvey, on cow dung (UWA 2039).

Family Boletaceae

Austroboletus occidentalis Watling, in Watling & Gregory p 104 (1986), as *Boletus lacunosus* Cooke & Massee, Mundaring Weir (UWA 1305): as *Porphyrellus cookei* Singer, Canning Dam (UWA 1869), Gleneagle (E*).

Boletus lacunosus see ***Austroboletus occidentalis.***

Re-collection: ***Boletus caesareus*** Fr. in Lehmann, Pl Preiss 2:134 (1846), Mundaring Weir (UWA 3384) (E). Gleneagle (UWA 3454).

Boletus multicolor Cleland, Trans R Soc S Aust 58:214 (1934). Two Peoples Bay (UWA 2652).

Boletus nigerrimus Heim, Rev Mycol 28:281 (1963). Crystal Brook (UWA 1852), Kings Park (UWA 2110); Quininup (UWA 2214).

Gyroporus caespitosus Cleland, Trans R Soc S Aust 48:247 (1924). Shannon River (UWA 3308).

Porphyrellus cookei see ***Austroboletus occidentalis.***

Family Coprinaceae

Coprinus cordisporus Gibbs, The Naturalist, London, 100 (1898). John Forrest National Park, on horse dung (UWA 2535).

Coprinus curtus Kalchbrenner, Grevillea 9:138 (1881). Nedlands, on horse dung (UWA 2537), Mundaring, on Kangaroo dung (UWA 2539).

Coprinus flocculosus De Candolle: Fr., Epicr p 245. (1838). John Forrest National Park, on horse dung (UWA 2534).

Coprrinus macrocephalus (Berk.) Berk., Outl Br Fungol 180 (1860). Wattle Grove, on horse dung (UWA 2533).

Coprinus pellucidus Karsten, Medd Soc Fauna & Flora Fennica 9:51 (1882). Wattle Grove, on horse dung (UWA 2540).

Coprinus radians (Desm.) Fr., Epicr p 248 (1838) Duncraig (UWA 2307), including the Ozonium stage.

Coprinus stercoreus Fr., Epicr p 251. (1838). Mt Dale, on Kangaroo dung (UWA 2531).

Coprinus vermiculifer Josserand ex Dennis, Kew Bull 19:112 (1964). Dwellingup, on Kangaroo dung (UWA 2532).

Panaeolus fimicola (Fr.) Quél., Enchiridion Fungorum p 119 (1886). Crawley (UWA 2514).

Panaeolus speciosus P D Orton, Notes R Bot Gdn Edinb. 29:1:110 (1969). Harvey (UWA 2567).

Family Cortinariaceae

Astrosporina asterospora see **Astrosporina imbricata**

Astrosporina imbricata Cleland, Trans R Soc S Aust 57:192 (1933). Crawley (UWA 1681), Gleneagle (UWA 2557). Horak (1979 p 190) indicates that this is the species to which *A. asterospora* Quel. *sensu* Cleland and *Inocybe murrayana* Cleland correspond.

Cortinarius archeri Berk., Fl Tasman t 181 f 7 (1880). Mundaring (UWA 2515).

Revision: **Cortinarius australiensis** (Cleland & Cheel) Horak, Sydowia 34:106 (1981). Previously listed as *Rozites australiensis* Cleland & Cheel.

Cortinarius austro-venetus see **Dermocybe austro-veneta**.

Cortinarius clelandii Smith, Lloydia 7:203 (1944). Dwellingup (UWA 3008). A *nomen novum* for *C. subcinnamoneus* Clel. See Ammirati (1975).

Cortinarius erythrocephalus see **Dermocybe erythrocephala**.

Cortinarius globuliformis Bougher, Trans Br Mycol Soc 86:301 (1986). Dwellingup (UWA 2919*).

Cortinarius lavendulensis Cleland, Trans R Soc S Aust 52:217 (1928). Dwellingup (UWA 2906).

Cortinarius ochraceus Cleland, Trans R Soc S Aust 51:301 (1927). Canning Dam (UWA 1991).

Cortinarius paleaceus (Weinm.) Fr., Epicr p 302 (1822). Gleneagle (UWA 2671).

Cortinarius rotundisporus Cleland & Cheel, Trans R Soc S Aust 42:96 (1918). W Australia (ZT 1152).

Cortinarius sanguineus see **Dermocybe erythrocephala**.

Cortinarius subarcheri Cleland, Trans R Soc S Aust 52:220 (1928). Jarrahdale (UWA 2016). Denmark (UWA 2323).

Cortinarius subcinnamoneus see **Cortinarius clelandii**.

Cortinarius vinaceolumellutus Cleland, Trans R Soc S Aust 57:191 (1933). Dwellingup (UWA 2907).

Cortinarius violaceus (L. ex Fr.) Fr., Sverig ätl gift Svampar t 58 (1861-68). Byford (UWA 2126).

Crepidotus eucalyptorum Cleland, Trans R Soc S Aust 48:242 (1924). Floreat Park (UWA 1225). Gleneagle (UWA 2573).

Crepidotus globigerus see **C. nephrodes**

Crepidotus nephrodes (Berk. & Curt.) Sacc. Syll Fung 5:882 (1887). Mundaring Weir, as *C. globigerus* (UWA 1434). Quininup (UWA 3410). Kings Park (UWA 3352).

Revision: *Crepidotus subhaustellaris* see **Melanotus hepatochrous**, Strophariaceae.

Crepidotus variabilis (Pers.) Kummer, Führ Pilzk p 74 (1871). Manjimup (UWA 3314).

Dermocybe austroveneta (Cleland) Moser & Horak, Beihefte Nov Hedwig 52:605 (1975). Gleneagle (UWA 2548).

Dermocybe erythrocephala (Dennis) Moser, Schweiz. Z Pilzk 50:166 (1972). Gleneagle (UWA 2542) = *Cortinarius sanguineus* sensu stricto Cleland (1934) = *Cortinarius erythrocephalus* Dennis, Kew Bull 1955 p 107 (1956).

Dermocybe splendida Horak, Aust J Bot Suppl Ser 10:33 (1983). Walpole National Park (UWA 2322) (ZT 79/307).

Descolea maculata Bougher, Aust J Bot 33:619 (1985). Floreat Park (UWA 2860*) (ZT 1843). Denmark (UWA 2897) (UWA 2914). Walpole (UWA 2916). Harvey (UWA 2915).

Galerina macquariensis Smith & Singer, Mycologia 50:478 (1958). Bull Creek (UWA 1256).

Hebeloma aminophilum Miller & Hilton, Sydowia 39:133 (1986). Kalamunda (UWA 2013) (UWA 2150*). Mundaring (UWA 2030). Quininup (UWA 2111).

Inocybe australiensis Cleland & Cheel, Trans R Soc S Aust 42:109 (1918). Mundaring Weir (UWA 1942, UWA 1669). Serpentine Dam (UWA 1546). Cleland's *I. serrata* and *I. granulosipes* are synonymous with this species (Horak 1980, p 26).

Inocybe fibrillosibrunnea Miller & Hilton, Sydowia 39:132 (1986). Kalamunda (UWA 2204*) (VPI*). Julimar (VPI).

Inocybe granulosipes see **Inocybe australiensis**.

Inocybe murrayana see **Astrosporina imbricata**.

Inocybe serrata see **Inocybe australiensis**.

Revision: *Rozites australiensis* see **Cortinarius australiensis**.

Tubaria rufofulva (Cleland) Reid & Horak, Aust J Bot Suppl Ser 10:29 (1983). Quininup (UWA 2080). Denmark (UWA 2333) (ZT). Two Peoples Bay (UWA 2663). Gleneagle (UWA 2669). As *Pholiota*, Cleland (1934 p 103).

Family Entolomataceae

Claudopus byssisedus (Fr.) Gillet, Les Hyménomycètes p 427 (1878). Karragullen (UWA 2952).

Leptonia incana (Fr.) Gillet, Les Hyménomycètes p 414 (1874). Mundaring Forest (UWA 2503). Gleneagle (UWA 2441). Gervasse (UWA 2433).

Family Hygrophoraceae

Hygrophorus cantharellus (Schw.) Fr., Epicr Myc p 329 (1838). Giants (UWA 2795) (VPI).

Hygrophorus laetus (Fr.) Fr., Epicr Myc p 329 (1838). Walpole (UWA 2590) (VPI).

Family Lepiotaceae

Lepiota acutesquamosa (Weinm.) Gillet, Les Hyménomycètes p 60 (1874). Quininup (UWA 3306).

Lepiota cristata (Fr.) Kummer, Führ Pilzk p 137 (1871). Mt Frankland (UWA 2338).

Lepiota gracilenta see **Lepiota konradii**.

Lepiota haemorrhagica Cleland, Trans R Soc S Aust 55:154 (1931). Mundaring (K).

Lepiota konradii Huijsman ex P D Orton, Trans Br Mycol Soc 43:283 (1960). Margaret River, as *Lepiota gracilenta* (Krombh.) Quél. (UWA 358). Mundaring Weir (UWA 1547). Gleneagle (UWA 2581).

Lepiota nigro-cinerea Cleland, Trans R Soc S Aust 55:153 (1931). Mundaring (K).

Leucocoprinus fragilissimus (Berk. & Rav.) Pat., J Bot Paris 2:16 (1888). Crawley (UWA 2828).

Family Paxillaceae

Paxillus corrugatus see ***Paxillus curtisii.***

Paxillus curtisii Berk. apud Berk. & Curtis. Ann Mag Nat Hist ser 2, 12:423 (1853). Gleneagle (UWA 2588) (VPI). Synonymous with *P. corrugatus* Atkinson.

Family Pluteaceae

Pluteus flammipes var ***depauperata*** Horak, Aust J Bot Suppl Ser 10:33 (1983). W Australia (ZT).

Pluteus pellitus Fr. : Pers., Synop Method Fung p 366 (1801). Pemberton (UWA 2591).

Pluteus villosus (Bull.) ss. Decary, Romagnesi, Bull Soc Mycol Fr 43:19 (1927). Julimar (UWA 1634) (UWA 1666).

Family Russulaceae

Lactarius clarkei Cleland, Trans R Soc S Aust 51:302 (1927). Virgin Jarrah, Manjimup (UWA 3310).

Lactarius eucalypti Miller & Hilton, Sydowia 39:127 (1986). Gleneagle (UWA 1719). Denmark (VPI*) (UWA 2341*). Walpole (UWA 2354).

Russula clelandii Miller & Hilton, Sydowia 39:128 (1986). Denmark (VPI*) (UWA 2364*).

Russula purpureoflava Cleland, Trans R Soc S Aust 51:301 (1927). Gleneagle (UWA 2628).

Family Strophariaceae

Hypholoma see ***Naematoloma.***

Revision: ***Melanotus hepatochrous*** (Berk.) Singer is the correct name for *Crepidotus subhaustellaris* Cleland. (Horak 1977). Perry Lakes (UWA 2522).

Naematoloma aurantiacum see ***Stropharia aurantiaca.***

Naematoloma sublateritium (Fr.) Quél. Champ Jura p 143 (1872). Dwellingup (UWA 354).

Re-collection: ***Pholiota drummondii*** (Berk.) Pegler, Darlington (UWA 3321) (K).

Pholiota gummosa (Lasch) Singer, Lilloa 22:517 (1951). Diamond State Forest (UWA 2180) (E), (UWA 2077).

Pholiota multicingulata Horak, Aust J Bot Suppl Ser 10:33 (1983). Western Australia (ZT 1160).

Pholiota rufofulva see ***Tubaria rufofulva,*** Cortinariaceae.

Psilocybe merdaria (Fr.) Ricken, Blätterpilze p 251 (1915). Kwinana (UWA 2027). See Miller & Hilton (1987). (-*Stropharia merdaria* (Fr.) Quél.).

Stropharia aurantiaca (Cooke) P D Orton, Trans Br Mycol Soc 43:381 (1960). Crawley, as *Naematoloma aurantiacum* (Cooke) Guzmán (UWA 2425). Brunswick Junction (UWA 2435).

Stropharia merdaria see ***Psilocybe merdaria.***

Stropharia stercoraria (Schum.:Fr.) Quél., Ench Fung p 112 (1886). Noble Falls (UWA 2529).

Family Tricholomataceae

Armillaria mellea see ***Armillaria luteobubalina.***

Armillaria luteobubalina Watling & Kyle, Trans Br Mycol Soc 71:79 (1978). Kings Park (UWA 1828) (UWA 1831). Two Peoples Bay (UWA 2636). Carinyah (UWA 2243). Floreat Park (UWA 2252). Esperance (UWA 1780). Records of *A. mellea* (Vahl ex Fr.) Kummer all appear to have been ***A. luteobubalina*** (Kile *et al* 1983).

Clitocybe asterospora (J. Lange) Moser apud Gams, Kleine Kryptogamenflora II p 52 (1953). Garden Island (UWA 1360).

Clitocybe gibba (Fr.) Kummer, Führ Pilz p 123 (1871). As *C. infundibuliformis* (Fr.) Quél. Yunderup (UWA 2446).

Clitocybe infundibuliformis see ***Clitocybe gibba.***

Clitocybe odora (Bull. : Fr.) Kummer, Führ Pilz p 121 (1871). Jarrahdale (UWA 2687).

Collybia abutyracea Cleland, Trans R Soc S Aust 55:156 (1931). Pemberton (UWA 1479).

Collybia butyracea (Bull. : Fr.) Kummer, Führ Pilz p 117 (1871). Giants (UWA 2363), Mundaring (UWA 2497).

Collybia dryophila (Bull. : Fr.) Kummer, Führ Pilz 115 (1871). Gleneagle (UWA 2592) (VPI).

Collybia elegans Cleland, Trans R Soc S Aust 57:187 (1933). Quininup (UWA 2094).

Collybia peronata (Bolt. : Fr.) Kummer, Führ Pilz p 115 (1871). Mundaring Weir (UWA 2830).

Conchomyces bursaeformis (Berk.) Horak, Sydowia 34:109 (1981). Pemberton (UWA 3020).

Delicatula crispula (Quél.) Pat., Essai taxon p 157 (1900). Wanneroo (UWA 2216)-*Hemimycena crispula* (Quél.) Singer, Ann Mycol 41:121 (1943).

Flammulina velutipes (Fr.) Karst., Medd Soc Fauna Fl Fenn 18:62 (1891). Dampier Peninsula (UWA 2771).

Hemimycena crispula see ***Delicatula crispula.***

Hohenbuehelia atrocaerulea (Fr.) Singer, var ***grisea*** (Peck) Thorn & Barron Mycotaxon 25:390 (1986). Eneabba (UWA 2833). Anamorph determined by Thorn & Barron (1986 p 394) as *Nematoctonus robustus* Jones.

Laccaria fraterna (Cooke & Massee) Pegler, Aust J Bot 13:327 (1965). Jarrahdale (UWA 3009). As *L. lateritia* by A. M. Young (1982).

Laccaria lateritia see ***Laccaria fraterna.***

Laccaria ohiensis (Montagne) Singer, Mycologia 38:688 (1946). Mundaring Weir (UWA 1361).

Lentinus concinnus Pat., Bull Soc Mycol Fr 8:47 (1892). Kununurra (UWA 3371).

Lentinus lepideus see ***Pleurotus australis.***

Lentinus strigosus (Schwein.) Fr., Syst Orb Veg 77 (1825). Swan River (K). Tweed River (K). Tutanning (K).

Lepista sordida (Fr.) Singer, Lilloa 22 p 193 (1951). Hollywood (UWA 2112); Kings Park (UWA 2593) (VPI).

Leucopaxillus lilacinus Bougher, Sydowia 39:17 (1986). Dwellingup (UWA 2898, 3014*), Newlands (UWA 3018).

Marasmius crinisequi F. Mueller: Kalchbrenner, Grevillea 8:153 (1880)-*M. equicrinis* F. Mueller apud Berk. Porongorups (UWA 743).

Marasmius equicrinis see ***Marasmius crinisequi.***

Melanoleuca cognata (Fr.) Konrad & Maublanc, Icones Selectae Fungorum 6:323 (1926). Churchlands (UWA 2620).

Mycena austrororida Singer, Ark f Bot 4:394 (1959). Boranup (UWA 3334).

Mycena galericulata (Scop. : Fr.) S.F. Gray, Nat Arr Brit Plants 1:619 (1821). Dwellingup (UWA 2500).

Mycena latifolia (Peck) Sacc., Syll Fung 5:268 (1887). Carinyah (UWA 2457).

Mycena speirea (Fr.) Gillet, Les Hyménomycètes. p 280 (1874). Kalamunda, in pine plantation (E).

Omphalia see ***Omphalina***

Omphalina chromacea Cleland, Trans R Soc S Aust 48:239 (1924). Mt Barker (UWA 1724), Walpole (UWA 2796) (VPI).

Omphalina ericetorum (Fr.) M. Lange. Med om Gronland 147 (11):25 (1955). Denmark (UWA 2345) see Kew Bull 15:75 Fig. 11.

Oudemunsiella longipes (Bull.) Moser, Z Pilzk 19:4 (1955). Floreat Park (UWA 1884).

Panellus ligulatus Horak, Aust J Bot Suppl Ser 10:32 (1983). Manjimup (ZT 1176*).

Pleurotus australis (Cooke & Massee) Sacc., Syll fung 9:46 (1891). Dwellingup (UWA 1869), Collie (UWA 2829). Specimens UWA 1854, 2084 and 2087 are also of this species and not *Lentinus lepideus* as stated in Part I of the Census.

Resupinatus trichotis (Pers.) Singer, Persoonia 2:1:48 (1961). Wanneroo (UWA 2208).

Tricholoma saponaceum (Fr.) Kummer, Führ Pilz p 133 (1871). Pickering Brook (UWA 2000), Gleneagle (UWA 2521).

Order Aphyllophorales
Family Clavariaceae

Clavicorona pyxidata (Fr.) Doty, Lloydia 10:38 (1947). Manjimup (UWA 2955).

Clavulina cinerea (Fr.) Schroeter, Krypt Fl Schles Pilze p 442 (1888). Julimar (UWA 2528).

Clavulinopsis miniata (Berk.) Corner, Clavaria p 378 (1950). Jandakot (UWA 897).

Ramaria fumigata (Peck) Corner, Clavaria p 591 (1950). Karragullen (UWA 3383).

Ramaria gracilis (Fr.) Quél., Fl Myc p 463 (1888). Barton's Mill (UWA 2834).

Ramaria ochraceosalmonicolor (Cleland) Corner, Clavaria p 611 (1950). Roleystone (UWA 484).

Ramaria sinapicolor (Cleland) Corner, Clavaria p 621 (1950). Gleneagle (UWA 2868), Pickering Brook (UWA 2928).

Family Coniophoraceae

Coniophora olivacea (Fr. : Fr.) Karst Hattsv 2:162 (1880). Collie, on jarrah (UWA 103).

Family Corticiaceae

Peniophoru giganteu (Fr.) Massee, J Linn Soc 25: 142 (1889). Nannup (UWA 2018).

Phanerochaete filamentosa (Berk. & Curtis) Karst. em Donk, Persoonia, 2:223 (1962). Manjimup (UWA 3478) (PDD 52483).

Phlebia celtidis W. B. Cooke, Mycologia 48:394 (1956). York (UWA 2511).

Phlebia merismoides see ***Phlebia radiata.***

Phlebia radiata Fr., Syst Mycol 1:426 (1821). As *P. merismoides*, Gleneagle (UWA 1928).

Family Hericiaceae

Laxitextum bicolor (Fr.) Lentz, Agric Monograph US Dept Agric 24:19 (1955). Karragullen, as *Stereum bicolor* (UWA 728), Manjimup (PDD 52481).

Family Hydnaceae

Hydnum rufescens Fr. Syst Mycol 1:401 (1821). Gleneagle (UWA 2631) (UWA 2667).

Phellodon melaleucus (Fr.) Karst., Medd Soc Fauna & Flora Fennica 6:15 (1881). Gleneagle (UWA 2523).

Phellodon plicatus (Lloyd) Maas G. Proc K Ned Akad Wet (Ser c) 69:321 (1966). Waroona dam (UWA 2626); Two Peoples Bay (UWA 2196), Walpole (UWA 2356), Gleneagle (UWA 2673).

Family Hymenochaetaceae

Asterostroma persimile Wakefield. Kew Bull p 372 (1915). Manjimup (PDD 52473).

Phellinus conchatus (Pers. : Fr.) Quél., Ench Fung p 173 (1886). Denmark (UWA 2594).

Phellinus fastuosus see ***Phellinus spadiceus.***

Phellinus nilgheriensis (Montagne) G. Cunn., Polyp NZ, p 226 (1965). Drysdale (UWA 2146).

Phellinus spadiceus (Berk) G. Cunn., Polyp NZ p 235 (1943). Drysdale (UWA 2143, 2145). Manjimup, as ***Phellinus fastuosus*** (Lév.) Ryvarden (PDD 52507).

Phellinus wahlbergii (Fr.) Reid, Contr Bolus Herbarium 7:97 (1975). Manjimup (PDD 52508-52511).

Phellinus zealandicus (Cooke) G. Cunn., Polyp NZ p 223 (1965). Karragullen (UWA 26).

Family Lachnocladiaceae

Dichostereum pallescens (Schw.) Boidin & Lanquetin, Bull Soc Mycol Fr 96:381 (1980). Quininup (UWA 3389), Manjimup (PDD 52474-52476).

Family Polyporaceae

Abortiporus biennis see ***Heteroporus biennis.***

Revision: ***Coriolopsis brunneoleuca*** (Berk.) Ryvarden. Norw J Bot 19:230 (1972). Prince Frederick Harbour (UWA 3000). In Census Part I as *Polystictus brunneo-leucus.*

Coriolopsis floccosus (Jungh.) Ryvarden, Norw J Bot 19:230 (1972). Beagle Bay, Dampier Pen (UWA 2999).

Gloeoporus adustus (Willdenow : Fr) Pilát, Atlas des Champignons de l'Europe 3:152 (1937). Karragullen (UWA 56).

Grifola berkeleyi (Fr.) Murrill, Bull Torrey Bot Club 31:337 (1904). Murdoch (UWA 1639).

Grifola colensoi (Berk.) G. Cunn., Polyp NZ p 95 (1965). Porongorups (UWA 337).

Heteroporus biennis (Bull. : Fr.) Laz., Rev Real Acad Cienc exact fisc nat Madrid 15:120 (1916). York (UWA 3011).-*Abortiporus biennis* (Bull. :Fr.) Singer.

Inonotus chondromyelus Pegler, Trans Br Mycol Soc 47:167 (1964). Pemberton (UWA 1416). Cunningham (1965 p 201) records as *I. dryadeus* (Pers. : Fr.) Murrill from Ivanhoe.

Inonotus dryadeus see ***Inonotus chondromyelus.***

Lenzites acuta Berk., in Hooker's London J Bot 1:146 (1842). Mitchell Plateau (UWA 2785), Winjana Gorge (UWA 2983).

Macrohyporia dictyopora (Cooke) Johansen & Ryvarden, Trans Br Mycol Soc 72:192 (1979). Pemberton (PDD 52482).

Melanopus infernalis (Berk.) Pat., Essai Tax Hymén. p 80 (1900). Mandurah (UWA 332), Ludlow (UWA 2161), Two Peoples Bay (UWA 2198), Pemberton (UWA 3327).

Perenniporia medulla-panis (Fr.) Donk, Persoonia 5:1:76 (1967). Bungle Bungle (UWA 3373).

Phaeolus schweinitzii (Fr). Pat., Essai Tax Hymén. p 86 (1900). Manjimup (UWA 2083).

Polyporus arcularius (Batsch) Fr., Syst Mycol 1:342 (1821). Dampier Peninsula (UWA 2770), Mitchell Plateau (UWA 2855). Kununurra (UWA 3372).

Polyporus basilapiloides (McAlpine & Tepper) Cleland & Cheel. Trans R Soc S Aust 43:18 (1919). Albany (PDD).

Polyporus elegans Fr., Epicr p 440 (1838). Prince Frederick Harbour (UWA 3004).

Polyporus hartmanni Cooke, Grevillea 12:14 (1883). Port Hedland (UWA 3374).

Polyporus philippinensis Berk., in Hooker's London J Bot 1:148 (1842). Mitchell Plateau (UWA 2724), Port Warrender (UWA 2725).

Polyporus sclerotinius Rodway, Pap Proc R Soc Tas p 108 (1918). Augusta (UWA 631). Boranup (UWA 1368), Manjimup (UWA 2394).

Polyporus tricholoma Mont., Ann Sci Nat Ser 2. 8:365 (1837). Port Warrender (UWA 2726).

Polyporus udus Jungh., Tidschr v Nat Gesch Phys 7:289 (1840). Bungle Bungle (UWA 2984).

Revision: *Polystictus brunneoleucus* see ***Coriolopsis brunneoleuca.***

Poria carneo-lutea Rodway & Cleland, Pap Proc R Soc Tas p 18 (1929). Margaret River (UWA 1642).

Revision: *Trametes versatilis* see ***Trichaptum byssogenum.***

Revision: ***Trichaptum byssogenum*** (Junghuhn) Ryvarden, Kew Bull 31:101 (1975). For *Trametes versatilis.*

Family Stereaceae

Stereum affine Léveille. An sci Nat 3:2:210 (1844). Manjimup (UWA 3012). Pemberton (UWA 3407).

Stereum bicolor see ***Laxitextum bicolor,*** Hericiaceae.

Family Thelephoraceae

Thelephora congesta Berk., J Linn Soc 13:168 (1873). Kelmscott (UWA 1528).

Class Gasteromycetes
Order Gautieriales
Family Gautieriaceae

Austrogautieria manjimupana Trappe & Stewart, Mycologia 77:676 (1985). Manjimup (CORVALLIS*), Gleneagle (UWA 2690) (UWA 2911), Pickering Brook (UWA 2837).

Order Hymenogastrales
Family Hymenogastraceae

Gymnomyces pallidus Massee & Rodway ex Massee, Kew Bull p 125 (1898). Coll CSIRO H159 (UWA 2553). Formerly *Octaviania pallida* (Massee & Rodway) G. Cunn.

Hydnangium archeri (Berk.) Rodway, Pap Proc R Soc Tas 1911:25 (1912). Jarrahdale (MELU).

Hydnangium carneum Wallroth, Dietrich's Flora Regni Borussici 7:465 (1839). W Australia (UWA 667). Collie (UWA 2656).

Hymenogaster albus (Klotzsch) Berk. & Br., Ann Mag Nat Hist Ser 1. 13:349 (1844). Manjimup (CORVALLIS).

Octaviania pallida see ***Gymnomyces pallidus.***

Rhizopogon luteolus Fr., Symbolae Gasteromycetum 1:5 (1817). Dwellingup (PERTH). This species has long been used in Western Australia for mycorrhizal inoculation of pines, see Kessell & Stoate (1936) p 7.

Zelleromyces australiensis (Berk. & Br.) Pegler & Young, Trans Br Mycol Soc 72:231 (1979). Kalamunda (UWA 1887).

Zelleromyces daucinus Beaton, Pegler & Young, Kew Bull 39:686 (1984). Jarrahdale (MELU).

Zelleromyces malaiensis (Corner & Hawker) A H Smith, Mycologia 54:636 (1962). Dwellingup (MELU).

Family Secotiaceae

Cystangium sessile (Massee & Rodway) Singer & A H Smith, Bull Torrey Bot Club 21:1-112 (1960). Perup (UWA 2544).

Montagnea arenarius (DC.) Zeller, Mycologia 35:409 (1943). Kurrawang, as *Montagnites candollei* (ADW). Lake Moore (UWA 2705).

Montagnites candollei see ***Montagnea arenarius.***

Order Lycoperdales
Family Geastraceae

Geastrum triplex Junghuhn, Tijdschr Natuurl Gesch et Physiol Leiden 1840 p 257 (1840). Two Peoples Bay (UWA 2019). Kings Park (UWA 3355).

Family Lycoperdaceae

Bovista brunnea Berk., Flora Novae-Zelandiae 2:189 (1855). Merredin (ADW) and Dowerin (Univ Syd) according to Cunningham (1944 p 143).

Bovista verrucosa G. Cunn. New Zealand J Sci Tech 23:171 (1942). Condingup (UWA 1071).

Calvatia candida (Rostkovius) Hollos, Termeszetrajzi Fuzetek 25:112 (1902). Kings Park (UWA 589), Mt Benia (UWA 1485).

Lycoperdon hiemale see ***Lycoperdon pratense.***

Lycoperdon pratense Pers. ex Pers. Syn Meth Fung 142 (1801). Bassendean, (UWA 2691), Esperance (UWA 1553). Cunningham (1944 p 146) lists as *Lycoperdon hiemale.* European literature commonly lists this species as *Vascellum pratense* (Pers. ex Pers.) Kreisel.

Vascellum pratense see ***Lycoperdon pratense.***

Order Nidulariales
Family Nidulariaceae

Cyathus stercoreus (Schw.) de Toni. Syll Fung 7:40 (1888). Brunswick (UWA 2413), Yanchep (UWA 2165).

Nidula candida (Peck) White, Bull Torrey Bot Club 29:271 (1902). Augusta (UWA 2563).

Order Phallales
Family Clathraceae

Ileodictyon cibarium Tulasne, in Raol, Ann Sci Nat Bot Ser 3, 2:114 (1844). South West Australia. T Muir, F 121 (K) See Dring (1980 p 56).

Revision: *Lysurus australiensis* see ***Lysurus cruciatus.***

Revision: ***Lysurus cruciatus*** (Lepr. & Mont.) Lloyd, Synopsis of Known Phalloids p 40 (1909). This is the correct synonym for *Lysurus australiensis. Lysurus gardneri* is not Australian. See Dring (1980 p 76).

Revision: *Lysurus gardneri* see ***Lysurus cruciatus.***

Family Gelopellidaceae

Gelopellis purpurascens Beaton & Malajczuk, Trans Br Mycol Soc 87:479 (1986). Jarrahdale (MELU*).

Family Hysterangiaceae

Hysterangium affine Massee & Rodway, Kew Bull 1891:127 (1898). Jarrahdale (MELU).

Hysterangium inflatum Rodway, Proc R Soc Tas 1917:108 (1918). Jarrahdale (MELU).

Family Phallaceae

Phallus aurantiacus see ***Phallus rubicundus***.

Phallus hadriani Pers. ex Vent. Kings park (UWA 1482).

Phallus rubicundus (Bosc) Fr., Syst Mycol. 2:284 (1822). Nedlands (UWA 318). Gosnells (UWA 320). Cape Naturaliste (UWA 2608). Description: Cunningham (1944 p 94), Dring (1964 p 15) and (distinguishing from *P. aurantiacus*) Dring & Rose (1977 p 747).

Family Protophallaceae

Protubera canescens Beaton & Malajczuk, Trans Br Mycol Soc 87:41 (1986). Ludlow (MELU*). Porongorups (UWA 547).

Order Sclerodermatales

Family Sclerodermataceae

Polysaccum? degenerans Fr., Lehmann Pl Preiss 2:139 (1846). Swan River around Perth (Herb Preiss No 2704*). The similarity to *Pisolithus tinctorius* of this species described as new by Fries is obvious, but synonymy should not have been assumed as was done in Part I of the Census.

Scleroderma paradoxum Beaton & Weste, Trans Br Mycol Soc 79:41 (1983). Jarrahdale (MELU).

Order Tulostomatales

Family Calostomataceae

Calostoma fuhreri Crichton & Willis, Vic Nat 103:4 (1986). Grass Patch (UWA 2959).

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Petrology and origin of beach sand along the Rottnest Shelf coast, Southwestern Australia

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Abstract

A petrological study of beach sands along the Rottnest Shelf coast of southwestern Australia shows that there is wide variety of grain types derived from a range of sources. The main grain types are quartz, lithoclasts, molluscs, calcareous algae, foraminifera, echinoids, felspar and heavy minerals. To illustrate regional variability in beach sand composition four main grain categories were used: quartz, felspar, lithoclasts and skeletons. The distribution of these grain types along beaches shows distinct regional patterns within each of the five sectors between Geographe Bay and Dongara, reflecting variation in source type, biotic assemblages and coastal processes. The Geographe Bay, Leschenault-Preston and Wedge I-Dongara sectors exhibit relatively uniform compositional trends. The remaining sectors exhibit marked compositional variation related to their rocky shores, pocket beaches, cusps and accretionary sediment cells.

Quartz dominates the Geographe Bay and Leschenault-Preston sectors, but overall there is a decline in quartz to the north. Skeletons dominate the Wedge I-Dongara Sector, but may be locally abundant in the other sectors where there are nearby seagrass meadows or rocky shores. Lithoclasts are abundant near sites of eroding coastal limestone. As a consequence, such as in the Cape Bouvard-Trigg I and Whitfords-Lancelin sectors, the distribution of skeletons and lithoclasts may be markedly restricted geographically. Regionally, there also is a decline in abundance of felspar and heavy minerals to the north. The results highlight several trends in beach sand composition that are useful in understanding littoral transport, coastal processes and coastal management.

Introduction

The study of sediment provenance is the investigation of composition, texture and distribution of grains within sediment bodies with a view to determining their source or origin. Such data can indicate the relative importance and relationships between potential sediment sources and suites, and can provide insight into whether sediments are relict, or actively transported from distant sources, or thoroughly mixed, *etc*. Sediment provenance is a well established technique to derive such answers (Earley & Goodell 1968, Carver 1971, Windom *et al* 1971, Scheidegger & Phipps 1976, Browne *et al* 1980).

The essence of specifically applying a petrologic approach in provenance studies, rather than a textural one, is that by use of compositionally diagnostic sand grains (particularly if their origin or source is discrete) it is possible to map the final distribution of grain types to indicate one or more processes. The occurrence, absence, or abundance of specific grain types may be due to: 1 transport into the site; 2 generation at the site; and 3 dilution at the site by other incoming grain types.

The widespread nature or otherwise of particular grains therefore can indicate the amount (or lack) of dispersion along a given transport pathway. Conversely, the occurrence of discrete pockets of sediment with specific grain types could signal no transport to and from the study site, or for skeletal grains, generation within the site and no transport from it. Petrologic/provenance studies thus provide information on the degree of dispersion/transport in the natural system by utilizing diagnostic grains of known source. The advantage of such studies over those that utilize artificially stained sand is that natural grains reflect patterns of transport and dispersion that have occurred over a long term.

A petrological/provenance study can be successfully applied to beach sands of southwestern Australia for a number of reasons. Firstly, there are many distinct grain types with variable sources and variable age. Secondly, the beach is the zone of maximum sediment transport, and hence dispersion pathways, or lack of them, can be highlighted by use of provenance studies. Thirdly, nearshore/inshore coastal processes result in sediment being transported onshore and thus the beach zone can reflect input from nearshore/inshore sources as well as those alongshore. Finally, because beach environments tend to produce sediments of limited textural variation, textural attributes (such as grain size, shape, and sorting) alone cannot resolve provenance patterns.

This paper describes the principles, methods and results of a sediment petrology study of beaches of the Rottnest Shelf coast of southwestern Australia. The relevance of these results to local coastal processes of transport also is discussed. The principles and methodology of provenance analysis presented are applicable to other coasts with similar compositional diversity of sediment sources, and can provide information useful for determinimg sediment budgets and coastal dynamics at various scales of reference.

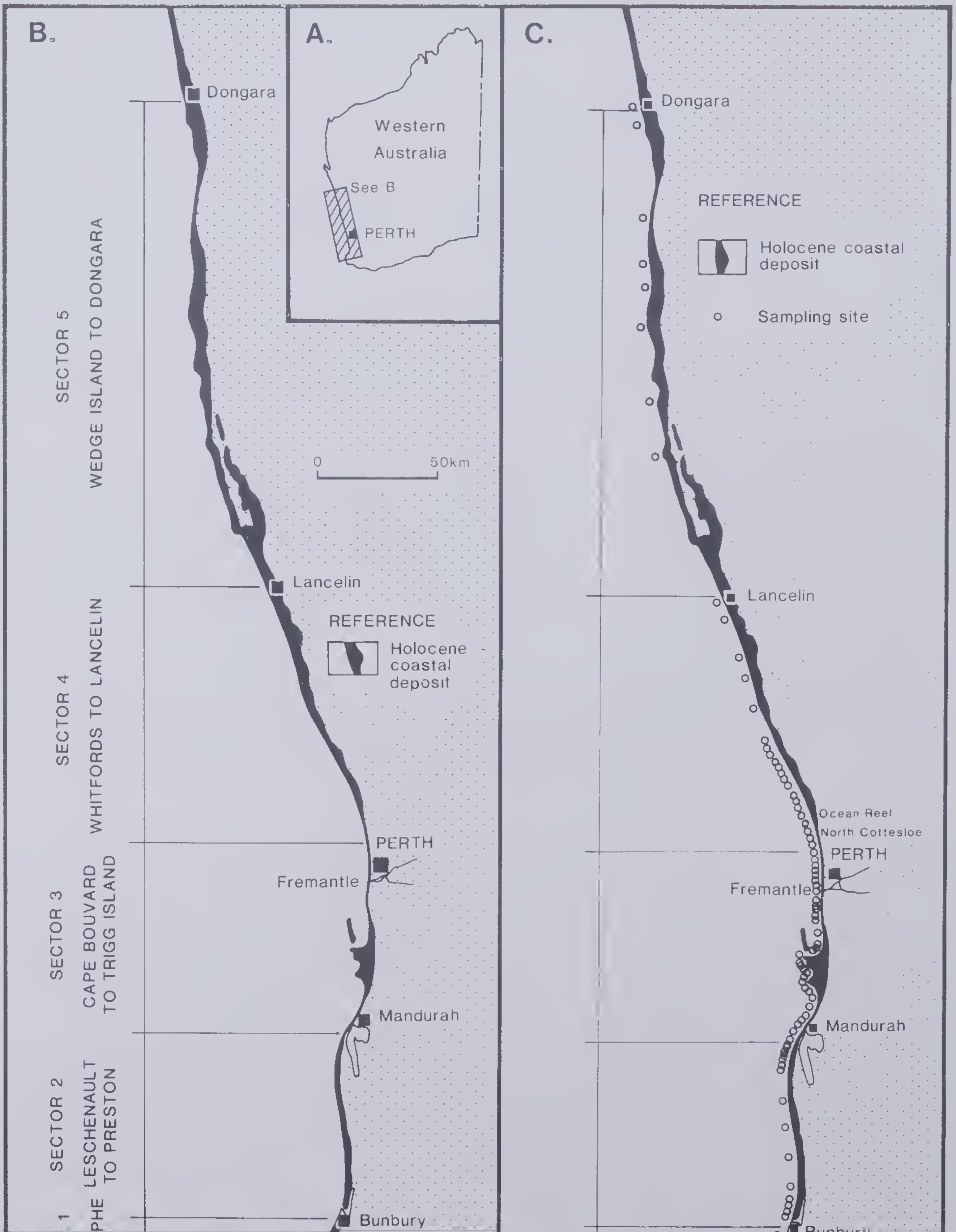

Figure 1 A & B Locality diagram showing coastal sectors of southwestern Australia (after Searle & Semeniuk 1985). C Location of sampling sites within each sector.

Methods

The sands of long uninterrupted beaches as well as the discrete pocket beaches of scalloped limestone rocky shores were sampled in this study (Fig. 1).

Three scales of sampling strategy were adopted. At the larger scale sampling was designed to encompass sediment compositional trends that distinguish the various coastal sectors of Searle & Semeniuk (1985). Sampling at this larger scale was carried out along the shore on a >10km spacing. All sectors were sampled in this manner. At the medium scale, in selected areas within each sector, such as the coast between Quinns Beach and Whitfords Beach, or between South Fremantle and Madora Bay, sampling of beach sands was carried out at a regular 0.5-1km spacing. At the smaller scale, in some selected areas of detailed study such as pocket beach systems along scalloped limestone rocky shores (Semeniuk & Johnson 1985), sampling was at intervals of 100-200m. At each sampling locality triplicate samples of surface sediment were collected in the swash zone within an area of 50m of beach shore length. Each sample was 100-200g in quantity and composed mainly of medium and coarse beach sand.

In the laboratory the replicate samples were dried in preparation for petrographic analysis. Because this investigation was a petrological study, the samples were not sieved so that the sediment composition across the full range of grain sizes could be determined in thin section. Each replicate sample was sub-sampled to yield *c* 2 cm^3 and impregnated with blue-dyed resin which accentuates the intergranular spaces and intragranular porosity under the microscope. Each of the impregnated blocks was cut into a standard thin section and stained for felspar. The thin-sections were petrographically analysed using a binocular polarizing microscope with an attached automatic point counter. For each slide between 300 and 500 points were counted (Galehouse 1971). Eight categories of grain were counted: quartz, felspar, carbonate lithoclast, mollusc, calcareous algae, foraminifera, echinoderm, and the heavy mineral suite. These were subsequently aggregated into five categories by amalgamating all the skeletal grains, as some skeletons were not found to be present in sufficient numbers. Each of the triplicate samples was analysed separately and a mean abundance (± SD) of grain types calculated for each sample site. The standard deviation was almost always less than 10% of the mean, indicating good reproducibility of sampling techniques and petrographic analysis, and relative homogeneity of sampling sites (Fig. 2).

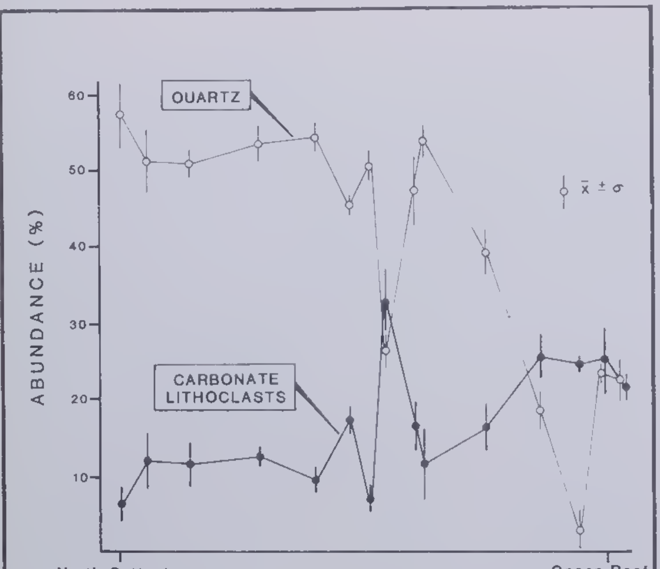

Figure 2 Detail of section of coast between Cottesloe and Ocean Reef showing quartz and lithoclast content of beach sands. Note the small standard deviation with respect to the mean abundance for these samples.

The identification of skeletal fragments in thin section is based on sections made from known standards. The standards provided definitive information on crystal size, crystal orientation, foliation, *etc* for each phylogenetic group as well as for distinct species. These standard thin sections supplemented information on identification of skeletal remains in thin section published by Bathurst (1975), Majewski (1969), Scholle (1978) and Flugel (1982).

Regional setting

The coastal zone of southwestern Australia is the seaward portion of the Swan Coastal Plain (McArthur & Bettenay 1960), and is composed of Holocene sediments and/or Pleistocene materials, which are part of the Phanerozoic Perth Basin (Playford *et al* 1976). The coastal environment of SW Australia encompassing the inner Rottnest Shelf that adjoins the Swan Coastal Plain has been subdivided into five sectors by Searle & Semeniuk (1985). Each sector has its own ancestral geomorphology, processes of sedimentation-erosion-transport, stratigraphic evolution, modern coastal geomorphology, and its own suite or pattern of distribution of sand grain types.

The coastal sectors are (Fig.2): **1** Geographe Bay Sector, a broad, open, north-facing embayment characterized by a low hinterland and simple submarine bathymetry; **2** the Leschenault-Preston Sector, characterized by a system of barrier dunes and lagoons, and a simple submarine bathymetry; **3** the Cape Bouvard-Trigg Island Sector, characterized by a complex bathymetry of marine ridge-and-depression morphology founded on Pleistocene limestone, and distinct Holocene sediment accumulations forming beachridge plains; **4** the Whitfords-Lancelin Sector, characterized by marine ridge- and-depression morphology, limestone rocky shores and isolated accretionary cusps of Holocene sediment; and **5** the Wedge Island-Dongara Sector characterized by a complex nearshore bathymetry of ridges-and-depressions, limestone rocky shores erosionally scalloped at a large scale, extensive shoreward migrating dune fields and asymmetric accretionary cuspate forelands of Holocene sediment.

Regardless of the variability of the geomorphology of the various sectors, the occurrence of a littoral zone, along which sand is transported, provides a common thread to the entire Rottnest Shelf Coast System (Searle & Semeniuk 1985). The shorelines are of 3 types: **1** sandy beaches, **2** limestone rocky shores alternating with sandy pocket beaches, and **3** limestone rocky shores. The extent and/or abundance of these shore types varies according to location: sandy shores are more common south of Perth; rocky shores are more common north of Perth. Beaches in this region have been subdivided on normal global criteria into shoreface, foreshore, backshore and beachridge/dune environments (Semeniuk & Johnson 1982). Rocky shore environments are complex, with cliffs, breccia wedges, shore platforms and breccia pavements (Fairbridge 1950, Semeniuk & Johnson 1985), but also have local sand accumulations in pocket beaches and sheets.

Grain types of the beach sands

Beach sands of the Rottnest Shelf coast contain the following main categories of grain types, many of which are fragments of siliceous crystals or marine skeletons: quartz; lithoclasts; molluscs; calcareous algae; foraminifers; echinoids; felspar; and heavy mineral suite. In addition, locally, there are fragments of barnacle, sponges, bryozoans and crustacea. A description of the main grain types and their potential source is presented below.

Quartz. Quartz grains occur in beach sands as medium to very coarse sand, well to very well rounded, commonly colourless but some are yellow because of iron compounds in microscopic cracks and pits on the grain surface. There are several potential sources of quartz sand on this coast. Yellow to brown quartzose sand occurs as sheets on parts of the inner Rottnest Shelf (Collins 1983, Searle 1984). These sheets were formed by the reworking of surficial subaerial sand deposits by the rising post-glacial seas. Unconsolidated Pleistocene sand dunes overlying the limestones along the coast are composed predominantly of quartz. The Holocene dunes of the modern coast also may contain up to 90% quartz (Semeniuk & Meagher 1981). Other lesser sources of quartz sand are the Pleistocene limestones; although variable, the quartz content of these limestones is commonly *10-20%.*

Lithoclasts. Carbonate lithoclasts are present as well-rounded, fine to very coarse sand-sized grains, and locally as gravel and cobbles. The lithoclasts typically contain sand-sized skeletal grains, pre-existing carbonate lithoclasts, minor quartz, and traces of heavy minerals. The lithoclasts are commonly cemented by a complex spectrum of microcrystalline, acicular and sparry carbonate cements. The ultimate sources of lithoclasts are the eroding rocky shores and islands of the coast. However, the unconsolidated Pleistocene and Holocene dunes in the region also contain variable quantities of lithoclast material (up to 50%). Although lithoclasts are originally derived from limestones, unconsolidated dunes are probably the most profuse source in the contemporary system.

Molluscs. Mollusc skeletons are present as sand and gravel fragments, and as whole skeletons, and vary in condition from pristine unbroken forms to well-rounded fragments. Mollusc material was identified mainly to class level. Some material was identified to generic and specific level for organisms that indicate specific environments; these skeletons include *Donax, Glycymeris, Brachidontes, Ninella, Marmostoma* and *Thalotia*, because they can reflect derivation from beach, rocky shore and seagrass meadow environments. For purposes of this paper discrimination of molluscs to generic or specific level is not provided, but such detail would be useful in studies located on small scale to medium scale sites.

The sources for mollusc grains are the benthic assemblages in the region. Seagrass meadow assemblages provide *Thalotia* and a host of other gastropod and bivalve species (Semeniuk & Searle 1985). Molluscs of the beach and inshore sand zone are mainly *Donax* and *Glycymeris.* Molluscs of the rocky shore include *Brachidontes, Ninella, Marmostoma, Dicathais* and *Haliotis.*

Calcareous algae. These skeletons occur as well rounded sand-sized fragments, or sand-sized disaggregated stem/leaf segments. The common calcareous algae are derived from seagrass meadows and algae-turf covered rocky shores. In this study, discrimination below the family level, even for those calcareous algae that are environment specific, was not attempted.

Foraminifera. Whole tests of foraminifera occur as sand sized components and are readily identifiable to generic and specific level. However, only *Marginopora* tests and fragments are common enough to be included in the study. The *Marginopora* are derived from seagrass meadow environments.

Echinoids. Spine and plate fragments of regular echinoids occur as sand-sized components, but are not common. They indicate derivation from a rocky shore or rocky pavement environment.

Felspar. Felspar grains occur as medium to very coarse sand. Most of the felspar occurs where rivers draining the granitic uplands have discharged sand onto the shelf during the Quaternary. Elsewhere felspar occurs in discrete patches of sand related to a relic offshore source. Felspar is also reworked from yellow dune sands overlying the coastal limestone.

Heavy mineral suite. The suite of grains termed heavy minerals includes rutile, ilmenite, tourmaline, garnet, leucoxene, monazite, magnetite, hornblende, augite and others (Baxter 1977). These minerals typically are fine sand- to very fine sand-sized. Their occurrence is widespread but they tend to occur most abundantly in Sector 1. In this study because of their overall low abundance when viewed regionally, differentation beyond "heavy mineral suite" was not warranted.

Other miscellaneous grains. Other grains, mainly skeletal, are described here only for completeness. These grains may be readily distinguishable in thin section and frequently are diagnostic of specific sources. The grains include barnacles, sponges, bryozoa, brachiopods, crustacea, vertebrate ossicles, intraclasts derived from beach rock, rock clasts eroded from basalt headlands (*eg* at Bunbury), and granite/ gneiss clasts and mica eroded from granitoid rock coasts of the Leeuwin Block. However, because of their low general abundance these grains were not used in this study.

Sources of the grain types for sediments in the region

There are numerous sources for the various grain types of the Rottnest Shelf coastal beaches. Some of these sources are currently manufacturing raw material; some are relict and slowly contributing specific grains; and some are eroding terrains yielding, again, a mixture of specific grain types. The main sources of the grains of the coastal beaches are: seagrass meadows; rocky shores; sandy beach and inshore zone; eroding yellow sand dunes; eroding estuarine deposits; eroding Holocene sand deposits; relict shelf sediment; eroding beach rock; and fluvial environments.

Seagrass meadows. Seagrass meadow environments, comprised of seagrasses, their epibionts and benthic fauna, are a major site of carbonate grain productivity in this region and thus a major source of skeletal grains. Seagrass meadow environments can produce some 2.2kg/m^2 of carbonate annually (Searle 1984) and much of this material accumulates *in situ*, contributing to an evolving seagrass lithofacies. However, as the banks prograde, shoal and lose their seagrass cover the sediment material becomes available for transport into the littoral zone. The carbonate grains generated include whole tests of foraminifera, bivalves and gastropods, and disaggregated or fragmented tests and skeletons of calcareous algae, bivalves, gastropods, bryozoans, sponges and crustaceans. The main skeletal fragments derived from seagrass meadows that are found in beach sediment are listed in Table 1.

Table 1

Relationship of grain types to the variable sources

	DERIVED GRAIN TYPES	
	sand	gravel
seagrass meadow	molluscs calcareous algae foraminifera	molluscs
rocky shore fauna	molluscs calcareous algae echinoids	molluscs echinoids
sand beaches and inshore zone	molluscs	molluscs
eroding limestone shores	lithoclasts lithoskels	lithoclasts lithoskels
eroding yellow sand dunes	quartz	
eroding Holocene sand deposits	molluscs calcareous algae foraminifera echinoids lithoclasts lithoskels quartz	molluscs lithoclasts lithoskels
relict shelf sediment	quartz lithoclasts	
fluvial environments	quartz felspar	
eroding estuarine deposits	quartz molluscs	molluscs
eroding beach rock	intraclasts	intraclasts

Rocky shores. The rocky shore environment yields 3 broad suites of grain types: whole skeletons and fragments of the resident biota; material from the eroding limestone; and quartz sand (Semeniuk & Johnson 1985). The biota inhabiting rocky shores is varied and includes calcareous algae, bivalves, robust gastropods, sponges and crustacea. The material eroded from the limestone shores are gravel and sand-sized lithoclasts and lithoskels; they include platey, rod-like, irregular and equant gravel-sized lithoclasts (Semeniuk & Johnson 1985), generally equant medium and coarse sand-sized lithoclasts, and whole to fragmented lithoskels (Read 1974). Some of this material is transported shore-wards or alongshore to accumulate in pocket beaches, but some also is transported to any adjoining long stretch of sandy beach in the region. Rocky shores also release quartz sand from the eroding limestone, from exhumed yellow sand-filled solution pipes, and from the quartz sand that blankets the coastal limestone.

Sandy beach and inshore zone. This environment of sand substrates supports benthic fauna of *Donax*, *Paphies* and *Glycymeris*, all of which contribute gravel-sized unfragmented shell and fragmented sand-sized particles.

Yellow sand dunes. Coastal erosion of the Spearwood Dunes invariably reworks the yellow quartz sand sheet that mantles the terrain. As a result quartz sand is dispersed into the shore environment.

Estuarine deposits. Coastal retreat may expose buried former estuarine deposits (*cf* Semeniuk 1985). These deposits are composed of inter-layered mud, shelly mud, shelly quartz sand and quartz sand. Grains derived from these deposits include estuarine shells and fragments, mud clasts and quartz sand, which are transported shoreward into the beach zone.

Holocene sand deposits. Erosion of earlier Holocene sand deposits (*eg* southern Becher Point, or Leschenault Peninsula) provides a wide range of grain types. The entire range of available grain types in the region may have been incorporated into a Holocene sediment sink, and later erosion will re-distribute these same grain types. The most common grains are quartz, skeletons and lithoclasts.

Relict shelf sediment. Sediment in the offshore/nearshore marine environment frequently is relict and is comprised of quartz sand or coarse skeletal sand and gravel. In most instances the relict sediment bodies are preserved because they are largely isolated from contemporary sediment sources. However, slow leakages of relict grains may be supplied to the shoreline by onshore transport.

Beach rock. Indurated beach sand referable to beach rock once formed in the shore zone can undergo erosion and degradation (Semeniuk & Searle 1987) to form boulder-, gravel-, and sand-sized intraclasts. These grain types, however, are not abundant.

Fluvial environment. Direct discharge of sediment from fluvial sources at numerous localities (*eg* Geographe Bay, Collie River, mouth of Swan River, mouth of Moore River) usually is limited by the occurrence of estuaries impounded behind coastal ridges or semi-permanent mouth bars. Entrained riverine sediment thus is retained in the quiescent estuarine environments forming deltas and bar complexes. However, some fluvial sediment consisting primarily of quartz and felspar is still discharged into the marine environment from the rivers of the smaller estuaries during periods of abnormally high flow. Fluvial sediment may also be incorporated into the shore environment where large scale coastal erosion has incised into pre-existing fluvial-estuarine deposits.

Discussion. It is apparent that a variety of grain types may be supplied from individual sources. This may lead to some confusion as to the source for a concentration pattern of a particular grain type. Conversely, some grain types originate from several sources. For instance, quartz is reworked and transported from rocky shores, yellow sand dunes, estuarine deposits, Holocene sand deposits, relict shelf sources, and fluvial environments. Thus the occurrence of local, high- concentration patches of quartz along a beach must be studied in context, by tracing the grains to the source by more general provenance mapping. Some grains are more specific as to source, for example lithoclasts, which ultimately indicate eroding limestones. Also in this regard, environment- specific shells can also be related directly to source (*eg* some species of *Thalotia* derived from seagrass meadow environments, *Ninella* fragments derived from rocky shores, or *Tellina* shells derived from estuarine deposits).

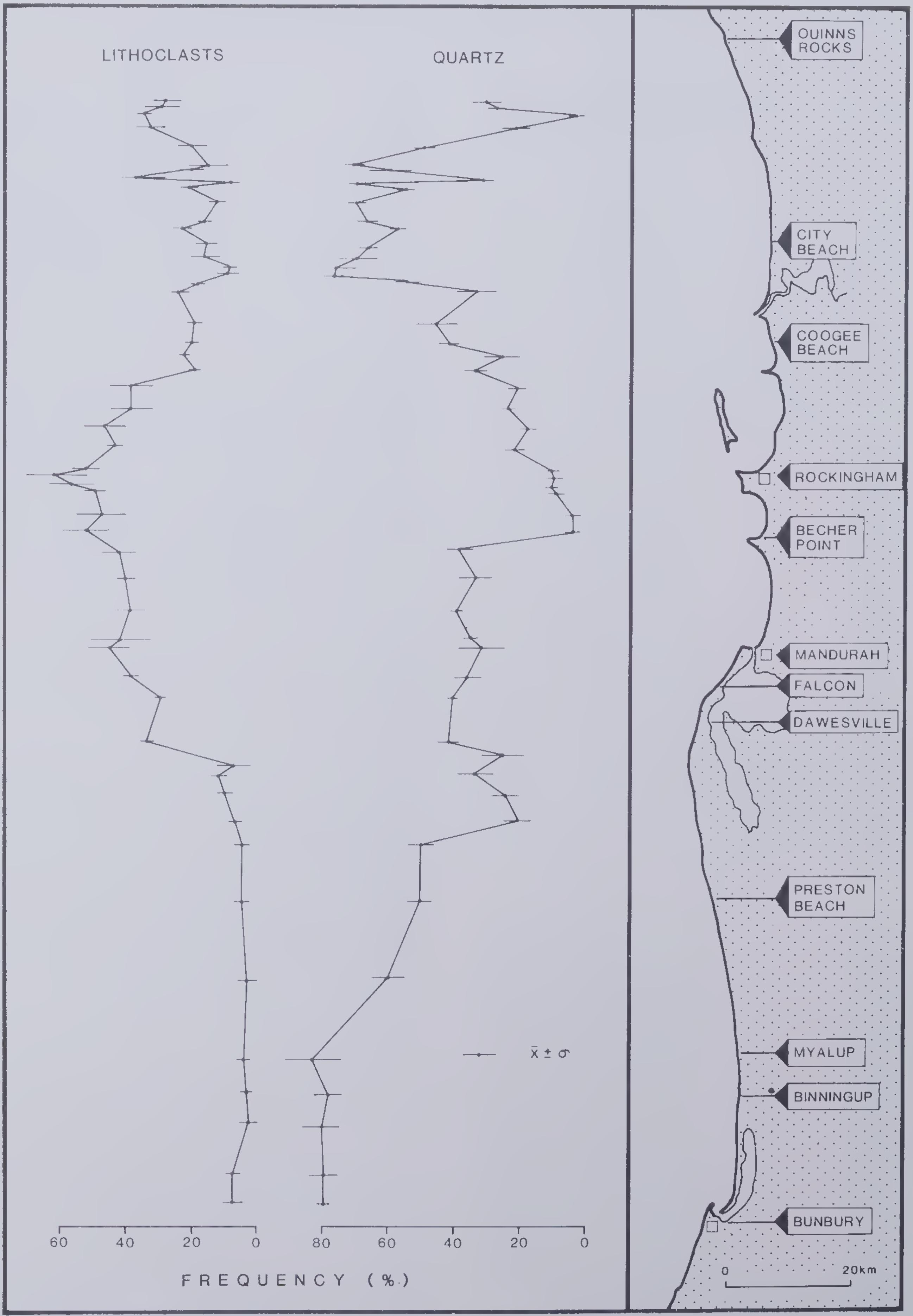

Figure 3 Variation of lithoclasts and quartz in beach sands along the coast between Bunbury and Eglington Rocks. Note the small standard deviation with respect to the mean abundance for the samples.

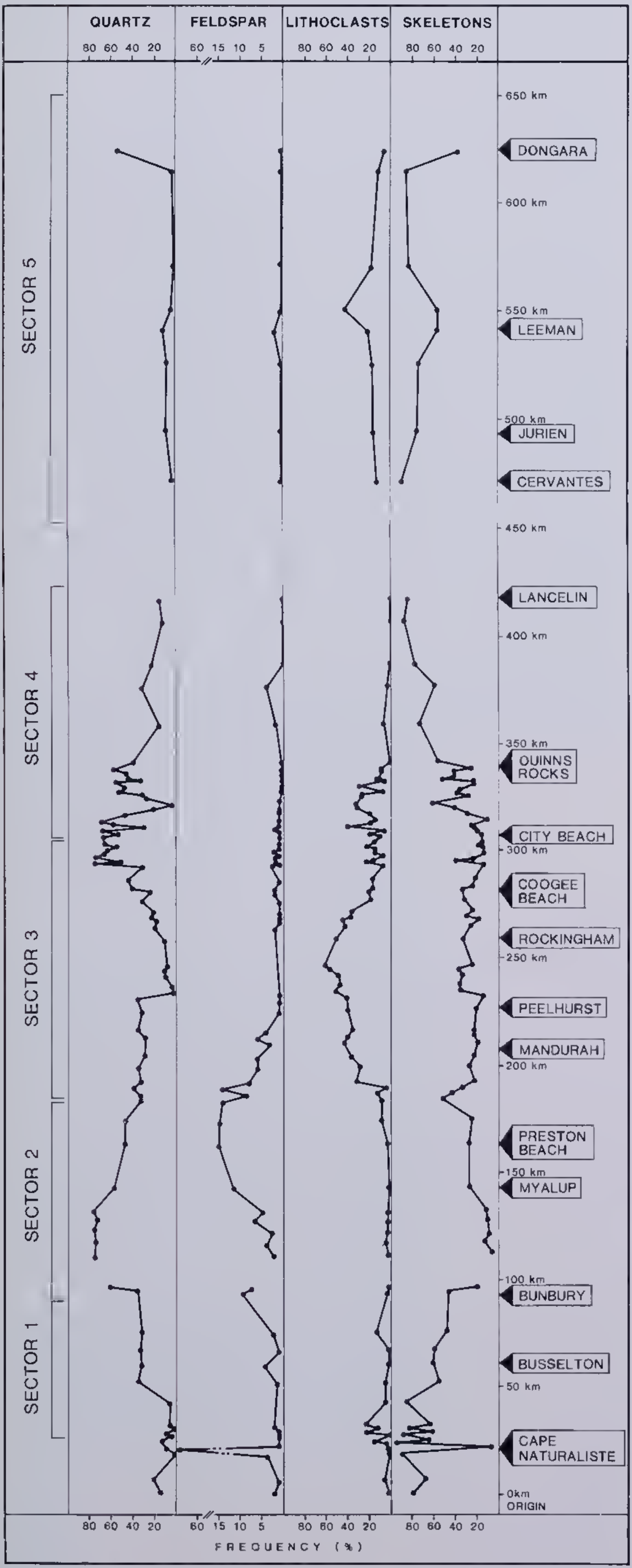

Figure 4 Compilation of results for all sampling sites, in all sectors, for abundance of quartz, lithoclasts, skeletons and felspar.

Regional & local distribution patterns of grain types in beach sand along the Rottnest Shelf coast

The distribution of sand grain types along the beaches of the Rottnest Shelf coast is presented in Figures 2-4. These results show distinctive patterns in each of the 5 sectors from Geographe Bay to Dongara. The results of a local provenance study, to illustrate the typical petrologic patterns of beaches in the Whitfords-Lancelin Sector, are presented in Fig. 2. The various distribution patterns of grain types in the beaches of the various sectors are interpreted below in terms of sediment provenance, supply and transport.

Geographe Bay Sector

Distribution of Grain Types. Data from the pocket beaches of the rocky shores of Cape Naturaliste and from the continuous sandy shore of Geographe Bay itself are discussed here. The pocket beaches of Cape Naturaliste show marked compositional variations between sample locations in adjacent pocket beaches 1 or 2km apart. The quartz component varies from 1 to 22%, felspar from 1 to 78%, lithoclasts from 2 to 26% and skeletons from 6 to 95%. In contrast, the Geographe Bay beaches exhibit a gradual change in composition at the regional scale. In the western portion of Geographe Bay, adjacent to Cape Naturaliste the sand contains high concentrations of skeletons (60-86%) and only minor concentrations of other grains. Progressing along Geographe Bay towards the east and north east, the skeletal component of the sands decreases to 40 or 50% and the quartz component increases to around 30 or 40%. Felspars and carbonate lithoclasts are present in minor concentrations that vary locally but do not exhibit a consistent trend; felspars vary from 1 to 4% and carbonate lithoclasts from 2 to 14%.

Interpretation of Distribution Patterns. The sharp contrast in sediment composition between the pocket beaches of the Cape Naturaliste shore indicates that there is little exchange between these beaches and the open shoreline of Geographe Bay. Local variation in sediment sources and supply cause the differences in sediment composition of the pocket beaches. For example, the occurrence of felspar- dominated lithologies at Bunker Bay contributes to the local concentration of that component in the adjacent beaches.

In contrast, the gradual change in sand composition along the shores of Geographe Bay indicates regional transport and mixing of sediments. The skeletal component is largely derived from the organisms inhabiting the extensive seagrass meadows that cover much of the floor of the bay (Searle 1978), and the supply of skeletons from the meadow to the shore occurs around the entire embayment. Consequently, the decline in skeleton content of sands from west to east is attributable either to selective transport of skeletons, or dilution by quartz sand supplied by the Vasse River system.

Leschenault-Preston Sector

Distribution of Grain Types. There is a significant hiatus in regional beach composition trends at Casuarina Point which separates the pattern of Geographe Bay from that of Leschenault-Preston. At Casuarina Point the beaches are bounded by headlands of basalt, and sands contain 76% skeletons, much higher than Geographe Bay to the south, or the shores of the Leschenault-Preston Sector to the north. In the Leschenault-Preston Sector, quartz dominates the beach sands. Although variable, the quartz content generally declines from 50 or 80% in the south to about 25% in the northern parts of the sector where there are local limestone rocky shores. Skeletons exhibit the reverse trend, generally increasing from less than 11% in the south to 38% in the northern portion of the sector. Lithoclasts form less than 10% of the beach sediment, except in northern localities with limestone rocky shores, where they reach up to 38%. Felspar concentration is variable but minor, locally reaching up to 16% at Preston.

Interpretation of Distribution Patterns. The compositional hiatus at Casuarina Point indicates that transport of sediment between the Geographe Bay and Leschenault-Preston sectors is limited. The coastal barrier in this sector is composed predominantly of quartz sand (80%) which is being liberated by erosion into the littoral transport system (Semeniuk & Meagher 1981, Semeniuk & Searle 1987), and prevailing conditions impell it northwards (Searle & Semeniuk 1985). As a result, quartz dominates the shoreline sands in the southern and middle parts of this sector. The compositional gradient towards the north of decreasing quartz and increasing skeletons is attributable to dilution of quartz by local sources of skeletons and lithoclasts. In the northern part of the sector, rocky substrates supply local sources of lithoclasts and support benthic organisms, which supply skeletal grains into the littoral transport system.

The variable felspar content of sand along this sector may be attributable to local anomalous deposits of felspar-rich sediments (possibly an old drainage channel) near Preston. Under prevailing conditions and storms the felspar is dispersed north and south. The more gradual decline in felspar to the north of Preston reflects the dominance of the prevailing northerly transport.

Cape Bouvard-Trigg Island Sector

Distribution of Grain Types. Between Cape Bouvard and Trigg Island the coast consists of sandy beaches interrupted by limestone rocky shores and this is reflected in the content of lithoclasts. South of Cape Bouvard in the Leschenault-Preston Sector, lithoclasts comprise less than 5% of the beach sediments. North of Cape Bouvard, the lithoclast content varies abruptly and locally between 0 and 45%. North of Mandurah, lithoclasts in the beach sands decline slightly to about 36% until rising again near Becher Point and Rockingham to 50 to 60%. North of Rockingham the lithoclast content progressively declines to less than 25% between Fremantle and Trigg Island. Skeletal grains reflect a similar trend to the lithoclasts.

The quartz content of beaches north of Cape Bouvard remains relatively constant at about 60% before declining abruptly to 30 to 40% near Falcon. At Becher Point the quartz content abruptly declines further from 30 to 40% to about 4%. The quartz content then steadily increases to between 64 to 76% at the northern extremity of the sector in the vicinity of Trigg Island. Felspar concentrations decline from 6% at Cape Bouvard to less than 2% for most of the remainder of the sector.

Interpretation of Distribution Patterns. The distribution patterns of grain types of the beaches in this sector clearly illustrate the local influence of productive seagrass meadow assemblages and extensive linear onshore and offshore limestone ridges (Searle 1984, Searle & Semeniuk 1985). Quartz-dominated sediment that is transported past Cape Bouvard from the Leschenault-Preston Sector is progressively diluted by carbonate sediment generated by the biota of rocky shores and benthic sand/ seagrass assemblages, or by the eroding limestones. Quartz contributes significantly to beaches, however, only as far north as Becher Point.

Beaches on the promontories closest to the eroding offshore ridges (Becher Point and Rockingham) contain the highest concentrations of carbonate lithoclasts. Elsewhere, benthic assemblages are the dominant sediment source. North of Fremantle, the supply of lithoclasts is limited to areas where there is exposure of lithified onshore aeolianite, and where the local seagrass meadow assemblages are less dense and, ultimately, absent. Consequently beach sediments are quartz-rich and tend to reflect the quartz-dominated dune sands that form the adjacent coast.

Whitfords-Lancelin Sector

Distribution of Grain Types. The Whitfords-Lancelin Sector consists of isolated sandy cuspate promontories widely separated by rocky coasts with pocket beaches. Two distinct distribution patterns are evident. Firstly, the pocket beaches vary greatly and abruptly in their content of quartz and lithoclast, with either being dominant; the skeleton content of the pocket beaches is minor but variable. Secondly, in contrast, the beaches of the sandy cuspate promontories are relatively homogeneous with skeletal grains forming a dominant component of the sands.

Interpretation of Distribution Patterns. The marked variation in sediment components between pocket beaches indicates the comparative lack of sediment exchange between adjacent pocket beaches. Consequently these beaches reflect local variation in sediment supply. Along these coasts, quartz is derived from the coastal limestones and from the quartzose sands overlying the limestones. The minor skeletal component is derived from the organisms inhabiting the intertidal to nearshore rocky environments.

The relative homogeneity of the composition of beach sands along the large scale accretionary cusps indicates the ready and efficient transport north and south along the uninterrupted cusp shores. The higher skeleton content of the sands reflects the presence of seagrass meadows that tend to inhabit the sheltered sandy substrates of the adjacent nearshore in the cusp loci. Abrupt compositional differences at the small scale between the cusps and adjacent pocket beach shores indicate little exchange of sediment between the large scale cusps and adjacent limestone rocky shores.

Wedge Island-Dongara Sector

Distribution of Grain Types. The limited number of samples collected in the northern half of the Wedge Island-Dongara Sector shows a general consistent pattern of sand composition, except near river mouths. The mollusc component is relatively high (>40%), the abundance of calcareous algae and lithoclasts are moderately but consistently elevated, *c* 25% and 20%, respectively, and the quartz content is generally low (< 10%). Felspar and heavy minerals generally are absent. At river mouths there may be a substantial input of quartz (*eg* 54% at Dongara) which significantly dilutes the other components.

Interpretation of Distribution Patterns. The overall uniform composition and apparent lack of compartmentalization of composition patterns at the regional scale within this sector suggest extensive alongshore transport and mixing of sediment types. This probably reflects the increased effect of sea-breeze generated windwaves as well as the progressive breakdown in shelter of offshore barriers (Searle & Semeniuk 1985). As a result, the sediment of pocket beaches along rocky shores and those of lengthy beaches of the large scale accretionary cusps are compositionally similar. Lithoclasts and molluscs derived from rocky shore environments are transported alongshore and freely mixed with calcareous algae and molluscs derived from seagrass meadow environments. The only major interruption to this pattern appears to be provided by rivers. Here, aeolian quartz sands of the hinterland are reworked, transported and discharged into the shore environment by rivers of the Murchison region.

Discussion and conclusions

Summary of distribution patterns

The distribution of sand grain types along beaches of the Rottnest Shelf coast shows several general patterns. Firstly, each of the 5 regional sectors between Geographe Bay and Dongara show distinctive patterns of grain type distribution, reflecting variation in source types, biotic assemblages and coastal processes. Quartz grains dominate the Geographe Bay Sector and Leschenault-Preston Sector for lengthy stretches of the coastline, but overall, there is a general decline regionally in quartz sand to the north. Within the Whitfords- Lancelin Sector quartz occurs in high concentration pockets only locally. Skeletal grains are locally abundant where there are nearby sites of extensive seagrass meadows or rocky shores, and lithoclasts also are abundant near sites of eroding limestone. As a consequence, the distribution of skeletal grains and lithoclasts may be markedly restricted geographically, and there may be a tendency for compartmentalization of sediment types containing these grains along the coast. Regionally there is a decline in abundance of heavy minerals to the north and felspar also is noted to occur mainly in the Geographe Bay and Leschenault-Preston Sectors.

Compositional trends of sands are uniform along the Geographe Bay and Leschanault Preston Sector. However, compositional trends are compartmentalized at the scale of the accretionary cells in the Cape Bouvard-Trigg Island Sector, and are markedly compartmentalized at the scale of pocket beaches and individual accretionary cusps in the Whitfords-Lancelin Sector. Pocket beaches along rocky shores, such as the northern part of the Leschenault-Preston Sector and throughout the Whitfords-lancelin Sector, also contain local high-concentration patches of lithoclasts. The skeletal grains on beaches of accretionary cusps in the Cape Bouvard-Trigg Island Sector and Whitfords-Lancelin Sector have sources in seagrass meadows in the nearby marine environment, and accordingly there is a concentration of molluscs and calcareous algae in these areas.

Significance of results

The results of this paper highlight several aspects of littoral transport that are important in understanding coastal processes, and that are useful in coastal management. Firstly, the results serve to identify the major pathways of sediment transport in the littoral zone of southwestern Australia. This has implications for coastal management in that it is possible to link coastal stability, or structures that result in coastal realignment, or activities that result in depletion of sediment supply, to some prominent and extensive pathways as identified by provenance studies. Secondly, as a corollary to the above, the results also indicate that transport in the littoral zone may involve lengthy and extensive pathways (or littoral streams) in some regions (*eg* the Leschenault-Preston Sector), but may be only small scale and compartmentalized in other regions (*eg* the Whitfords-Lancelin Sector). This aspect also has implications for coastal management in that the design of coastal structures and the management of coastal processes must be designed specifically to the various coastal sectors or sub-sectors in the region. Sediment transport rates and transport styles from one locality accordingly should not be indiscriminately applied to other areas, and should not be viewed as necessarily indicative of regional patterns.

Thirdly, the results indicate that there are various sources of sediment available for beaches, and that these can vary in their storage volumes and supply rates. However, it is also possible that the variation in composition and the gradual changes in abundance of specific grain types in beaches can indicate or reflect the varying coastal processes involved in supplying, transporting and emplacing the various grain types. This aspect of beach sand petrology, when used in conjunction with other coastal process information, can provide valuable insight into the long term aspects of coastal history, transport, or coastal stability. Finally, sediment provenance, when used in conjunction with other studies such as stratigraphy, oceanography, accretion/erosion rates and geomorphology, can provide an indication of volumes of sediment being transported along the littoral zone.

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